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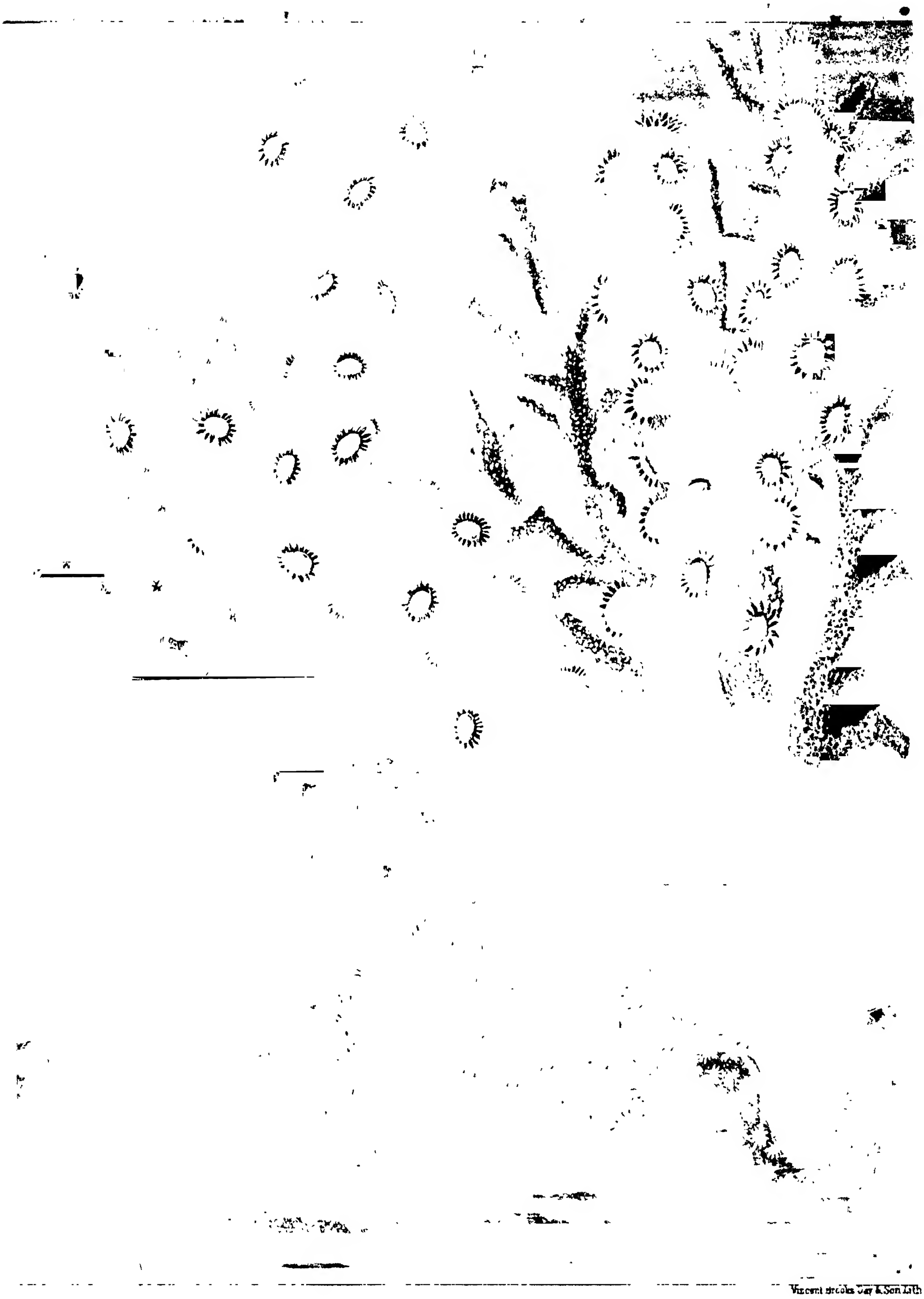

GROUP OF CORALS.

SCIENCE FOR ALL

EDITED BY

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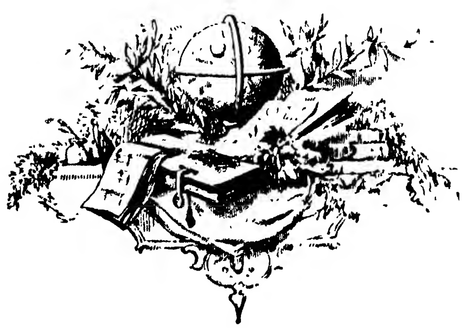
ILLUSTRATED.



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CONTENTS.

LIST OF ILLUSTRATIONS.

CORALS AND THEIR POLYPES.

By Professor P. Martin Duncan, F.R.S.

SOME years ago, a very beautiful exhibition took place at the Royal Society, during one of the annual gatherings of scientific and representative men. A tank of sea-water had a glass side in it, and a beam of light was thrown on to the surface of the water, and it passed down below and came out through the transparent plate. There was an apparatus which forced air into the water, and the myriads of minute bubbles and the clear water were intensely illuminated, the air globules looking like points of silver, and the fluid like luminous opal. Placed on the back of the tank, was a mass of dark-coloured rock, the surface of which came within six inches of the glass plate; and on the stone were living things of surpassing beauty. They were of a brilliant light orange colour, some being of a darker shade; they were sufficiently transparent to let the light come through their tender tissues, and they were in the shape of short cylindrical stems surmounted by a star; or, rather, the stems were sloping downwards, their star-like ends drooping gracefully. About half the size and length of a lady's little finger, they moved slightly, expanding their stars and growing longer when a stream of air-bubbles came close to them, and they contracted and became smaller when the light faded. The stars had rays on them like those of a daisy in position, and there was a round place in the midst. The light shone through the fleshy body of the stem, which had radiating structures in it, and a long central mark.

The numerous stems and stars, crowded as they were, did not come in contact. Each one seemed to be independent of its fellows in its slight movements. Yet this was not the case; for on the cessation of the bright light and the occurrence of a shake, the whole of the orange-tinted colony became dull in tint, and smaller, and finally seemed to retire. After this simultaneous and general movement had persisted for awhile, a honey-combed look came over the face of the rock, and only a faint tinge of yellow could be seen on a white surface. By-and-by the stems and stars began to be visible again, to increase in size, and in half an hour hundreds of them were stretched out to their utmost and revelling in the highly-aërated sea-water. It was a spectacle never to be forgotten; and some of the visitors had a similar, but grander, sight brought before their remembrance. Stimulated by the unexpected appearance of the pretty drooping stars, memory led their thoughts far away and to the remote torrid Pacific. A broad ocean, a surf breaking on a circular rock with a few cocoa-nut trees on it, and some under-wood; a placid lake within, and a sea beyond, constituted the scene; and the mind saw, in its pleasant memories, a perfect flower garden of stems and many-coloured stars flourishing on the rock beneath the rushing waves. As the remembrance became vivid, the splendour of the distant scene recalled itself. The shallow rocky floor on the verge of stupendous depths, was tenanted by beds of starry forms, some small, others large—the daisies and dahlias of the place, some white, grey, green, blue, red, purple, or orange in tint, or variegated or splashed with other colours, and gold, and silver, and black. Here and there a branching mass stood in the "mind's eye," reaching to the very surface of the water, and its tints were orange, yellow, red, and pale blue, and on it were myriads of stems and stars. Just out of the water and occasionally covered, were rounded blocks, whose stems, brilliant green centrally, had their rays all close together.

The remembrance of the dark-coloured blocks of stone and the white sand of the beach, recalled the common name of all these living things and their stony groundwork,—for they were corals, and it was a coral island. On a previous evening, and shortly after H.M.S. *Porcupine* had returned from her cruise in the North Atlantic Ocean, a collection of very elegantly shaped and beautifully chased, embossed, and fragile, but hard stony-looking things was exhibited. They were white

and had no living structures on them, but they were covered by, or they consisted of, cup-shaped bodies with stalks, and the cups had within them radiating plates. Some of these came from 1,200 fathoms, or 7,200 feet, and from off the oazy sea floor, others had been brought up from 90 to 600 fathoms from off a rocky sea bed, and many had been plunged up to their necks in mud. They were alive when they were first brought up on board, for they were then covered with a delicate membrane, which resembled, more or less, that of the yellow and orange stems and stars already noticed.

The thermometers which were let down when these stony things came up, denoted, that deep down, the temperature was that of freezing water, and there are proofs that the pressure of the sea was great at the depths. These pretty relics of the ocean floor were the hard parts of corals belonging to the same great natural history group as those forming coral reefs and islands, but differing from them in many interesting particulars. They were deep-sea corals. Many of the naturalists who examined them could not but remark that some of the dwellers in the great depths were not unlike small stony things covered with a delicate tissue, and presenting the appearance of a very flat little sea anemone, which is found in the caves and natural grottoes in the limestone of Devonshire, at the seaside, and which the tide rarely uncovers. These stars have stony cups beneath them, and they are known to people who sell things for the aquarium as "madrepores." They are corals of the shore, and they do not form vast collections as in the tropics, but are solitary. Thus there are reef-building corals, deep-sea corals, and shore corals; and all have many similar points of construction, whether they are small or large, single or made up of a vast number, or branching like small trees. When in life and in full vigour there is no doubt that they all resemble flowers somewhat, and, indeed, the ancients and many of the modern naturalists, down to the time of Peyssonnel, considered them to be of a vegetable nature, or that the hard parts were petrifactions out of sea-water. Peyssonnel sent a communication to the Royal Society of London in 1751, and demonstrated the animal nature of coral.

Everybody is aware that there is another dweller in the moderately deep parts of the Mediterranean and of some other seas, which is very precious for its beautiful red colour, and which is popularly called "coral." Necklaces, ear-rings, brooches, and many kinds of ornaments are made up occasionally of this beautiful, hard, and more or less branching "coral." Its purity and colour gave the title of "coral lips" to what a Transatlantic, realistic, mechanical-minded savant has called "the kissing apparatus of the maiden;" and its hardness has recommended it for the "coral and bells" of teething infants. But this coral—the *corallium* of Theophrastes—is unlike the other dwellers on the reef, shore, and in the deep sea mud, in its construction and method of growth. It belongs to the same great part of the animal kingdom, but it is placed, especially from its method of growth, and from its having a different numerical relation of the rays of its stars, in a different section from the true stony corals.

The red coral, when freshly brought up from depths of from 100 to 600 feet, is in the shape of a stunted tree, which has a broad base attached to something, a short thickish stem, and short stunted branches, becoming thinner at their ends. This arborescent stem, which may be intensely red or pale, is covered with a film of living matter, and when it is examined under exceptional and very rare circumstances, star-shaped bodies, with eight rays extending from a centre, where there is a mouth, are seen on it. The slightest rough washing, will remove this living structure and its stars, and barely a trace of

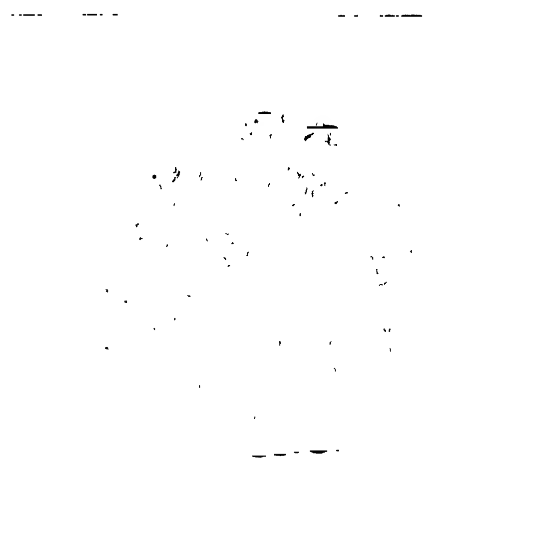

Fig. 1.—Magnified Cross Section of a Stem of the Red Coral.

their former existence is left on the hard red coral beneath. The red coral, in fact, forms a kind of base or foundation-support to the living tissues.

The stars of the polypes are not let into it, and the red substance is not formed in the midst of the star tissue. On the red coral are wavy lines and slight grooves, but none of it goes into the tissues of the soft cups, which are terminated by the stars, and which contain the organs by which food is digested and the eggs are formed. Now, suppose a stem of the red coral is cut across, and a thin slice is cut and polished and examined under a moderately high power of the microscope. The appearance presented is very beautiful, and it is evident that the coral was once a slender rod, which became thick by the growing of layer after layer around it (Fig. 1).

Again, travellers to India by the Red Sea, should they have the opportunity of coming near or landing on some of the islands, will notice that much of the beach sand and stone is red; and that just under the water, great rounded masses of red stone, covered with minute stars, are seen. The red sand consists of the fragments of the masses, and these are of a dull red tint, and consist of innumerable small pipe-stem-like tubes, placed side by side, and each set arises from, and is covered by, a kind of confusion of red substances and tubes (Figs. 2, 3).* The tubes are open at the top, but there are no plates in them converging from the edge to the centre, and they may be compared with cut straws. The polype lives in them, and when fully displayed emerges its upper part in the form of a tube, terminated by a star with eight serrated rays and a central mouth. The soft tissues of the minute animal extend from polype to polype, and the hard supporting tube structure, or skeleton, is formed by and within them. This is the Organ Coral, or Tubipora, and its intensely red skeleton is furnished with polypes of lighter tints, and which are often blue, green, white, or reddish.

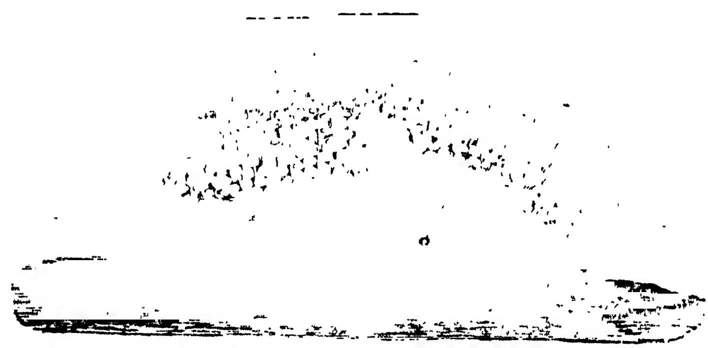

Fig. 2.– The Organ Coral (*Tubipora musica*).

Fig. 3.– Organ Coral, partly Expanded.

These three kinds of coral are separated by the naturalist in the scheme of Natural History classification, because their anatomy differs, but the titles Stony Coral, Red Coral, and Organ Coral, will probably always be given to them popularly. They really belong to different groups of an important order of the animal kingdom; but, in order to comprehend this, it is necessary to consider minutely the nature of the structure of the true stony corals.

If one of the corals with the yellow polypes† already mentioned be examined, or if some small Devonshire corals be kept in an aquarium and studied from time to time, it becomes evident that the soft and coloured flower-like portions, and the hard white substance they cover, are most intimately connected. Moreover, the resemblance of the simple or solitary coral from Devonshire to a common sea anemone is very striking, but there are no hard parts within this last common sea-side object. Microscopically, there is much in common, however, between the anemone and the soft part of the coral, and both are exceedingly irritable, and can swell out or diminish very remarkably in size.

The first thing which strikes any one who is desirous of studying the stony corals during their lifetime, is that (taking a simple form as the example)‡ they are more or less cup or goblet-shaped, and that a fleshy disc, with a hole in the middle, and surrounded by one or more rows of rays or feelers (tentacles) covers the top. This is the *tentacular disc*, and the hole, which is usually longer than broad, is the mouth. The disc is a

* In the Plate (*see* Frontispiece) the orange-coloured corals belong to a Mediterranean kind (*Astroides calycularis*). The dark branching coral is *Dendrophyllia nigrescens*, from the Red Sea and the Seychelles sea-floor. The white coral in the background is *Madrepora formosa*, a Pacific reef coral; and so is the stumpy branching green *Porites*. The rounded coral in front is *Favia pallida*, from the Fiji Islands; and that with the brilliant colours is a compound form, whose calices are some-
Above these rounded
and above these is a
which are some corals
wing from stolons.

† *Astroides calycularis.*

‡ *Caryophyllia Smithii.*

flattish membrane, and when seen from above, is usually coloured in rings, and has a set of markings which go from the mouth to the margin where the tentacles are.

These are in one or more rows, and are of various sizes, but all are more or less cylindrical, hollow, and have rounded tips. They are, with few exceptions, peculiar in their number. In very young corals there would be six, in larger ones twelve, and in adults twenty-four, forty-eight, ninety-six, and more in number. The number can be perfectly divided by six; or, in other words, the tentacles are in multiples of six. The tentacles, whatever may be their size, are not fringed or marked with minor ones on their sides, but are plain. When flourishing, the polype projects or hangs down a short distance from the hard part, and a kind of tube is produced. This is continuous at its top with the edges of the disc outside the tentacles, and below it is attached to the cup or tube-shaped hard part, being continued over its outside. All that the eye can see, distinctly, on the surface of the tube and tentacular disc, is the outside skin, or *ectoderm.*

The mouth opens somewhat widely occasionally, and shows an irregular bag-like space, at the bottom of which is a whitish structure, hard to the touch, and covered with a fine layer of soft substance. Dissection shows that there is a round edge or lip to the mouth which is capable of distension and contraction, and that beneath it there is a shallow rounded cavity or stomach, with folds on the sides, leading to a larger one, or perigastric or visceral cavity, whose lower membrane covers the white substance. These cavities, one beneath the other, are very central, and *spaces* open into the lower one all around it, and lead up to just beneath where the bases of the tentacles are attached to the disc. The tentacles are hollow, and communicate with the *spaces*, and these open into the cavity, so that any water or substances coming in by the mouth may be dispersed in and around these central spaces and over the membranes which form them. All the tissue of the inside of the lips, of the stomach and general cavity, and of the inside of the tentacles, belongs to the inner skin, or *endoderm.* So that the soft parts are made up of an outer and inner skin, and there is some intermediate substance uniting them and having to do with the hard parts.

Now, if the coral be removed from the water, the swollen out tentacles gradually diminish in size, and after a few minutes only a glaze of animal matter, consisting of the two skins and intermediate tissue, which have parted with much of the water usually contained in their constituent parts, is seen covering the white, hard, stony coral. If the soft parts be scrubbed off, it can be easily examined.

The hard parts of the animal consist of a cup, or tube-shaped main portion, which is closed below and open above; it contained the stomach and other membranes, and supported the tentacular disc; and it has been explained that the outer membrane once covered it outside. On looking down into the top of the cup, a central portion is seen like the axle end of a wheel in position, and radiating from it on all sides, to the edge of the cup, like so many spokes, are solid plates of carbonate of lime. These are slender, but although only their tops can be seen, they really extend down the cup. Above, they are curved, and on their sides within the cup, there is much pretty ornamentation. These plates are called *septa,* and there is a small space on either side of each one which also goes to the bottom of the cup. These spaces are called *interseptal spaces.* The central body, or *columella,* is made up of a number of pieces of carbonate of lime in the shape of twisted ribbons, and between it and the septa are some arched bodies like small septa, and which are called *pali.* The septa are in contact with the cup at its sides, which are thick, ornamented and solid, and constitute the *theca.* Outside the *theca* there are projections running down the coral corresponding in position with the *septa* within, and which are called ribs or *costæ.*

Now, the sides of the septa, the inside of the *theca,* the top of the *columella*—that is to say, all the inside of the hard parts of the cup—are covered with an extension of the inner skin, or *endoderm;* and the outer part is of course covered by ectoderm; so that the only space on the coral where there is any room, is between the septa or in the *interseptal* spaces, and also above the *columella.* In life there is a fold of skin in each interseptal space, in which the eggs are developed, and each of those spaces opens into the visceral cavity as already explained. Again, every tentacle and the under part of the disc are in relation to the septa and interseptal spaces.

But how is the soft polype connected with the hard carbonate of lime of the pretty radiate looking cup, so as to produce this bulky and heavy skeleton? Take a living specimen and place it in a very weak mixture of hydrochloric acid and water, and great bubbling will go on for awhile during the evolution of carbonic acid gas from the carbonate of lime, and the production of a soluble

chloride of lime. After a while all the solid coral will be found to have gone, but there remains besides the skins and intermediate substance, a film, bulky and yet very fragile, and which is a soft tissue which once pervaded every part of the hard coral, and which may be shown to be a continuation of the structure intermediate between the outer and inner skins, and of these tissues also.

By making a thin slice of the hard part of a fresh coral, and after polishing it until it becomes transparent, the microscopic nature of the substance can be shown. First of all, in the septa, a thin film of soft tissue evidently separated each one into two lateral halves, and crystals of carbonate of lime commenced in the tissues and radiated outwards. The crystals are long prisms placed close, and side by side. Similar groups of crystals may be seen all over the coral, their arrangement producing the outside and inside ornamentation also. The coral is not formed like structureless mineral, nor is it made up of hard grains, but of regularly placed crystals of a mineral called arragonite—a form of carbonate of lime. It must be understood, however, that an organic soft tissue has played its part in depositing these crystals. In fact, the carbonate of lime of the coral is deposited according to the same philosophy by which the phosphate of lime of our own bones is put in its proper place, out of a fluid which represents so much bread and meat digested. It is a product of life, and not of simple deposition from sea water. Hence, as the soft coral polype flourishes, more arragonite is deposited, and the soft and hard parts grow in due relation to one another. In the simple corals, like the Devonshire *Caryophyllia*, the growth does not proceed above that of the size of a small half-thimble, but in some of the compound forms, such as are represented in the coloured plate [*see* FRONTISPIECE], the size is considerable, and thousands of simple corals may be said to be collected together, as carbonate of lime collectors and depositors. It is therefore necessary to proceed to consider how a compound coral is formed, and then to study the minute anatomy and physiology of some kinds.

The branching coral (*Dendrophyllia nigrescens*), which occupies the centre of the coloured plate, lives in tolerably deep water, and it will be noticed that its dark black green body is covered, here and there, with cups, each carrying a tentaculiferous disc. The little white tentacles have a yellow hue within them, the disc is green, and the mouth is dark in tint, and, as a matter of fact, during life the whole outside has a delicate ectoderm or outer skin on it.

Every cup, or *corallite*, as it is called—the whole mass being the *corallum*—has its star of tentacles hiding the septa of the inside, and although separated by much space they are all alike. The corallum is tall, and contains a considerable quantity of carbonate of lime, and it increases by a process called budding.

This branching coral is brittle, and when a long piece of it is held in the hand and shaken sharply, it will snap off; but it lives in deep water, out of the range of violent currents and waves, and catches by means of its tentacles, the minute shelled creatures which jostle against them.

Very different are the compound or reef-building corals which dwell near the surface, and flourish amongst the surf of the grandest waves in the world, or in the quiet lagoon beyond, where, however, the sea may be troubled. They require strength, lightness, and the power of rapid growth; for the rush of a wave would snap off a solid and heavy piece, and there is always some wear and tear going on. The strength and lightness are produced in a manner which modern engineers have striven to imitate in buildings exposed to similar conditions. The original cup or tube grows upwards, and has the anatomy of the simple coral; but after growth has proceeded for a while, a new hard structure is formed inside the animal. A slender floor is formed across the interseptal spaces, and all the space below it is shut off, and the soft parts which were once down there cease to grow, and others cover the top of the floor. A set of cellular compartments is thus formed, the animal growing up, and leaving so much dead coral behind. Time after time this growth of floor (or *dissepiment*) proceeds, and in an individual coral (a *corallite*) of two inches in height, a score or more of them will be found. The polype, in each instance, withdraws into the higher chamber, lives on the top of its new floor, and leaves the rest below, all shut up like a cell, untenanted and dead. Hence, in very large masses of coral, a foot or more in height, it is only the top quarter of an inch, or even less, that is tenanted by the soft parts, all the rest is partitioned off, and is, to all intents and purposes, a mass of very strong carbonate of lime, built up of uprights and cross pieces, all very strong and light.

But long before the original coral grows many of these cross floors, it produces from its outside by budding, other corallites like unto itself, and they grow up with the parent in height and strength.

On the outside of each one, there are the ribs (*costæ*), and the outside skin reaches from one corallite to another, and produces within itself a flat layer of carbonate of lime, on a level with a corresponding flat internal floor. As the corallites all grow up together, more cross outside pieces (*exotheca*) are formed, so that, at last, a true reef-building coral has a multitude of tubes connected by cross pieces, and each has a cellular structure within. The growth is rapid, and the truly living part is quite at the top; and if a piece is broken off by a wave, or nibbled off by the parrot-fish, the upward growth soon compensates. In fact there is a constant struggle on the part of these corals, to grow just under the surface water, and they are ever wearing, dying, and growing. In the quieter water, such rounded forms as those represented towards the bottom of the coloured plate flourish, but even in their instance, the separate corallites, each with its coloured tentacular disc, are fitted with internal floors, and sometimes there is the *exotheca*, but most frequently the walls or sides of the individuals fuse together. The fusing, or the presence of *exotheca*, is constantly noticed in bulky reef makers, but they are not required in solitary corals, or in those which live in deep water. The internal floor is, however, found in the deep water kinds sometimes, and it appears to enable them to increase in height.

In a classification of the corals, those without and those with these structures, are separated.

It must be remembered that not only has the coral to produce the skeleton, but that it has to grow its soft tissues, to obtain food to do this, to digest and separate protoplasm for its tissues, and carbonate of lime for its new parts, to respire, and to increase and multiply. Watch a coral in an aquarium abundantly supplied with good aërated sea-water;—its tentacles move occasionally slightly, expand, contract, and sometimes the disc and all the tentacles close up. Touch the tentacles, and they seem to stick for an instant and then to close rapidly. The water is full of food in the form of minute beings, and evidently the coral catches many which are very minute, and occasionally entraps a larger and visible one. The tentacles move together on to their victim, which is stuck to one or more of them, and the mouth expands, and finally the food disappears into the stomach.

The water being fresh, the tentacles are fully expanded, and it is evident that the coral polype respires by their means. Catching prey, moving, and respiring, require special structures, and they, and the colouring matter of the creature, are all present.

The outside skin of the cups is continued over the tentacles, which are hollow, and on to the disc. Now under the microscope, three or four sets of bodies or cells constitute it. Firstly, there are some globular bags or cells with very delicate walls, which contain a glairy fluid or sticky secretion which covers the fingers on handling some corals, and entangles some kinds of prey. Secondly, there are minute cells with many contractile hairs or cilia on them; these move strongly in one direction, and return to their original position, like the closing and opening of one's fingers, and produce currents in the water in contact with the skin. Thirdly, there are thousands of long cells, almost sausage-shaped, placed side by side. They point outward where there is a little spike-like projection. Each of these elongated cells contains a fluid which makes it tense, and also a delicate hair-like thread curled up in a pretty tight spiral. The thread is a continuation of the outside membrane of the cell, pushed in like the inverted finger of a glove, and twisted. The slightest unusual pressure will cause this thread to be turned out with a rush, and it evidently has some stinging or paralysing power on minute creatures, and on delicate human tissues. These are called *nematocysts*, or thread cells. The last kind of structure consists of globular cells, containing granules of colouring matter. All these cells are close together, and form a moderately tenacious tissue. Inside the polype and within the mouth and the gastric cavity, the spaces and under the tentacles is the inner skin, and it is made up very much after the fashion of the outer. Between the skins is the intermediate tissue, and it contains young cells and a number of muscular fibres and connective tissue. The muscular fibres are simple threads of highly contractile substance, and some are in bundles, and are long, being placed lengthwise up the tentacles, and from their base to the mouth of the disc; and others are in rings, encircling the tentacles and doing the same to the mouth and disc. By the contraction, expansion, and union of action of the muscles, all the movements are produced.

The prey is stung, paralysed, and killed; it is moved by the tentacles to the mouth, and is dissolved in the stomach by the secretion of the inner skin. Water and small things are drawn over the surface into the mouth and about the stomach by the active cilia cells, and also much air contained in the sea. The cells are so thin, that their contents not only pass more or less from set to set, but are also aërated when in contact with the rapidly moving

water. The respiration is of the simplest kind, and is mainly carried on inside the tentacles; but if the water is impure the coral soon dies. The circulation is perfect, but there are no vessels or special appliances; the digestion is rapid, and the partitioning of the digested matters into tissue, cells, and arragonite crystals is as wonderful and as incomprehensible as all other vital processes. Ever feeding, ever growing, carbonate of lime must be deposited, and hence the huge dimensions of reef-building corals which are exposed to the rush of the tropical sea, crowded as it is with minute life.

Hanging between the septa and in the interseptal spaces, and suspended from the underneath part of the disc, are folds of tissue, on the inner side of which are curious worm-like bodies. These are crowded with the thread-cells, but they have nevertheless the duty of producing the future young. As the coral grows upwards and increases in size these egg-producing parts increase in number, and as they do so, the tentacles increase and also the septa of the hard parts.

Now this increase is a very remarkable part of the story of the life of a coral, for it does not take place by chance or irregularly, but by a definite arithmetical law.

After the young coral has grown sufficiently to secrete the hard substance within its tissues, six plates or septa are formed, and a corresponding number of tentacles, water-spaces, and egg-producing mesenteries. These are the primary septa. As growth proceeds, six others appear; starting from the wall, midway between two primary septa; each grows inwards and thus divides the original inter-space into two and determines the development of another set of tentacles and two egg organs. There are then twelve septa and the second six are called the secondaries. Soon a third set appears intermediate, and a repetition of the contemporaneous tentacle and egg-organ growth occurs. These tertiaries bring the septa up to twenty-four; and the next set, growing also in the intermediate manner, develops into forty-eight and ninety-six, and sometimes more.

The older the septa the larger are they; the same rule is true with regard to the tentacles. It is this multiplying by six that gives the great radiant symmetry to the masses of stars in large corals. The exceptions to this rule were very common in the ages of the past, and there are often peculiar defects in many recent species, but still the law is very general.

Some corals have their hard parts singularly dense and impervious, and the septa and walls are without visible pores. The rounded corals in the coloured plate are instances. But the green specimens with two short rounded branches and many minute stars on them, and the large white branching form in the background have their hard tissue full of pores, so that the soft tissues penetrate the walls and septa, and the whole coral is very light. These are examples of the *Perforata*, and the others, just noticed as being solid, are some of the Aporosa. The Perforata grow with great rapidity, and are especially able to withstand the violence of waves.

The last of the structures of the corals which has to be noticed, refers to a singular and not often told chapter in their history.

Some corals which live in tolerably deep water, the base being attached to a stone, are exquisitely ornamented with beadings, flutings, and curved lines from top to bottom, and the delicate soft tissue covers over all, and dips down into the hard part. There is probably not much motion of the sea at the depths where they are found, but there are living things there which trouble the coral, and which in return are troubled by it. A worm which grows to a considerable size, and forms a dense fibrous texture around its body as a kind of house, begins life by plunging into the thin tissues of the young coral when it is a few lines in length, and the feelers of the worm on the top of its head appear at the side of the calices of the coral. The worm certainly cannot get anything out of the coral by way of nourishment, but it occupies a part of the structures of its growing "host," as it may be called.

But when the coral has got very large and thick, it grows so rapidly that the worm is constantly being encased, and has to get all the food it can, to keep pace with its unwilling protector. Sooner or later, the worm gets walled up, and on breaking the coral, the encased worm with its fibrous tissue may be found inside the hard dense skeleton. In fact it would appear, until the matter is thought out, that the worm had bored into the coral. Other corals living on reefs, or in the mud of shallow seas, are attacked by a host of enemies, and a certain amount of protection is afforded them by the growth around their bases and parts likely to be covered with mud, of a thick coating of carbonate of lime in the form of what is called *epitheca*. This layer covers up the outside ornamentation of some of the simple corals in a most curious manner, and is a plain but unique cover, and is produced

in and over a soft tissue, which appears to come from the base of the coral and extend upwards. It flakes off readily in some kinds, but is more like a varnish in others, and as its soft tissue soon dies the minute creatures which bore into or live on the coral do not thrive there. There are some corals which have bases as large and as flat as a small plate, and they rest on mud or soft ground under the sea, and their epitheca covers the hidden base only, and is formed into concentric rings. On the other hand, some large corals, like the *Goniopora columna* (Fig. 4), in which the epitheca, looking very much like dried mud, covers the stem up to the commencement of the calices, and is seen to be covered here and there with shells. Nevertheless, the epitheca will not keep out very persevering parasites. Thus, there is a boring shell, which drills in some extraordinary manner right into the coral, and lives, ever pressing onwards, and leaving a tunnel behind, caring little for the epitheca. But it does protect the coral to a considerable degree from a vegetable parasite—*Achlya penetrans.* This is a microscopic fungus, which, after resting on the outside of the coral, secretes carbonic acid gas, and this dissolves some of the carbonate of lime of the skeleton, forming a soluble bi-carbonate. Soon a small tube is got into the hard structures by this dissolving process, and the growth of the fungus, and in the course of time thousands of minute passages are thus chemically formed in the mass, rendering the coral fragile and readily broken. This fungus attacks every part of the coral, and probably feeds on the animal matter which always exists in the forsaken portions of the hard parts.

Fig. 4.—*Goniopora columna.*

One of the most remarkable things about the corals, is their symmetry of growth; not only do they increase in bulk, but they do this according to definite laws, for every species of compound coral has its own peculiar direction of growth and shape. Thus the brainstone corals form large hemispherical masses, the madrepores branch and rebranch, and may attain many feet in length or height; the *Dendrophylliæ* are often wonderfully stem and bush-shaped; and there are flat tabulate and round-topped kinds amongst the reef-builders. So definite is this symmetry, and so persistent is the shape of every kind of coral, that these peculiarities are important in the classification of the genera, most of which may be recognised by their special method of growth, and ultimate perfection.

The Stony Corals belong to the great group of animals which includes the Red and Organ Corals, and it is characterised by there being but one opening in the hollow soft polypes for food, and the outward passage of the eggs and immature young. It is called the Cœlenterate Order (*Koilos*—hollow, *enteron*—bowel). The Stony Corals have their hard parts formed within their structures, by an inner derm or skin, and the tentacles are in

multiples of six, and are not fringed with others. They are called *Madreporaria*. The Red Coral has its hard part formed as a kind of core, and is covered by the soft parts, whose tentacles are eight in number, and are fringed. It is one of the *Alcyonaria*, belonging to the family of the *Gorgonidæ*.

Finally, the Organ Coral is provided with eight fringed tentacles, but its peculiar life-structure places it amongst the *Alcyonaria* in a family of its own.

BURNT-OUT VOLCANOES.

BY PROFESSOR T. G. BONNEY, M.A., F.R.S.

A LITTLE south of the centre of France, a great plateau of granitic and schistose rock rises, island-like, above the surrounding secondary strata. A considerable part of it attains a general elevation of about 2,500 feet, and declines rather from east to west. Its surface, as a glance at a geological map will show, is studded with numerous patches of volcanic rock, with lava streams and craters, many of which are in a remarkably perfect condition.

Here, in Auvergne, more easily than in any other place readily accessible from England, volcanoes can be examined while their natural features are comparatively fresh and unchanged, yet without interference from the sulphurous exhalations and discharges of an active vent. Here we have our "subject," to use the language of the surgeon, ready for us in the first stage of dissection, giving us the clues by which we can interpret the more obscure signs of volcanic action in the earlier geological periods.

We cannot precisely determine at what date the volcanic fires became extinct in Auvergne. As will presently be seen, ages elapsed between the first and the last outbursts, during which there were probably long intervals of quiescence, and it is likely that the subterranean furnaces would not cease action simultaneously over the whole region, but would break forth, now here, now there, with an expiring sputter.

There is some reason to think that one or two isolated outbreaks occurred so late as the fifth century of the present era, though that is a matter on which there is much dispute. At any rate, there is a passage in the writings of Sidonius Apollinaris, Bishop of Clermont, in Auvergne, and another in those of Alcimus Avitus, Archbishop of Vienne, which must either be accounted pieces of the most exaggerated bombast, or must record some of the phenomena of a volcanic eruption.

Before describing a few of the facts which this region teaches us, a sketch of its geological history may be in itself instructive.

It is not till the Tertiary Period is considerably advanced that we meet with any very distinct records of volcanic action in Auvergne. Then, in the Miocene epoch, the inequalities of the plateau appear to have been occupied by large fresh-water lakes; the surface of these being probably some 2,000 feet above the present level of the sea. At this time volcanoes broke forth on the plateau, ejecting mounds of scoria, and flows of lava, till at last the shores of the lakes, and the marls which had gathered beneath their waters were in many places sealed up beneath great sheets of basalt. Then the level of the lakes was gradually lowered. As the water fell, the tributary streams, which took their rise among the volcanic hills, deepened and enlarged their channels, until the foundation rock was again laid bare, and portions of the basaltic sheets were left, forming bastion-like crags high above the re-excavated beds of the lakes and the floors of the glens.

The volcanic energy appears to have been for a while quiescent. At last, however, it awoke, and a number of volcanic vents opened in a sporadic way; some upon the plateau, some on the floors of the newly excavated valleys. These, though discharging scoria and lava in considerable quantities, were smaller than those formed in the preceding period; they resembled the volcanoes of the Phlegræan Fields, rather than the cone of Vesuvius—attaining no great elevation, emitting no extensive flows of lava. It is with these last that we shall at present deal. They exhibit no marked signs of physical change. Vegetation has masked or rain has furrowed some of the cones; lichen and moss, herbs and shrubs, have occasionally softened the asperities of the lava stream, and, in some cases, the river has again carved for itself a passage through the obstacles, and has regained its ancient channel; but on the whole, the district remains very much in

the condition in which it was when the last shower of ashes was ejected from the last expiring crater.

These volcanic hills, in the Auvergne district, bear the name of Puy. We will take our examples from the chain which studs the eastern edge of the granitic plateau, near to the town of Clermont Ferrand. It will at once be observed that in these hills there are marked differences of outline; the majority being truncated cones, the usual form of volcanic craters; while a few are flattened domes, something like—to use an unpoetical simile—the upper half of a plum-pudding. The latter, such as the Puy de Dôme, the highest summit of the group, on examination, prove to be without sign of a crater, and to consist wholly of a peculiar variety of trachyte; their precise geological age and mode of formation are uncertain, but probably these hills (with other trachytic masses of greater size) are much older than the adjoining cones.

Of these cones one of the most perfect is called the Puy Pariou. Viewed from the south it appears a well-defined cone, rising some 700 feet above the base, with steeply sloping sides (the angle being about 35°), wholly composed of volcanic scoria. Grass and ling have in many places grown over this, but there are others still bare. On reaching the summit we find ourselves on the rim of a perfect crater, some hundred yards deep and about ten times as much in circumference, with the ridge still in places so sharp that there is hardly room to stand upon it. Herbage clothes the interior of the crater, and, as Scrope observes, it is a singular spectacle to see a herd of cattle quietly grazing above the orifice whence such furious explosions once broke forth.

Fig. 1.—Puy de las Solas and Puy de la Vache (Extinct Volcanoes in the Puy de Dôme Chain).

By descending on the northern side we perceive that the structure of this Puy is not so simple as it previously appeared. We there find a crescentic ring of scoria, of no great height, clasping the base of the cone, and from between the two a stream of lava issues, which extends for a considerable distance towards the east. In this outer and broken ring we have, in all probability, a record similar to that which we have already seen in Somma and the cone of Vesuvius;* namely, the remains of an earlier crater, which has been, in part, destroyed by the formation of a newer one;

* "Science for All," Vol. II., p. 237, et seqq.

though here the older crater is on a smaller scale than in that historic mountain, and the interval between the formation of the two was very likely not nearly so long as we know was the case in the Italian mountain. The outer crater was formed first. Possibly its walls were built up to a greater height than the remaining part now attains; then came a series of explosions, hurling its light materials into the air, and afterwards building up the inner pile, from the base of which a lava-stream was ejected. The discharge of this may, indeed, have immediately preceded, instead of succeeded, the formation of the second cone. At the present day, on the flank of Vesuvius, we may see a case resembling this, in the line of craters which were formed during the eruption of 1861. A fissure then opened out in the mountain side; over the upper part of this a line of small craters of scoria was formed, and from the lower a stream of lava issued forth and flowed down the slope.

That at the base of the Puy Pariou at one place seems to have welled up against the remains of the older crater-ring, and rests for a short distance upon it like a breaking wave, frozen before it fell. As we walk along the surface of this stream towards the valley we find that though occasionally overspread by vegetation, it presents the same appearance as those which have issued from Vesuvius. It rises into ridges; it is furrowed by wrinkles; it is crested with slaggy prominences and rough lumps; it is strewn with volcanic dust and scoria, like hard cinders or bits of "pulled bread," blackened at the fire; it wells up against projecting eminences; and at last, when it has reached the brow of the plateau, pours in cascades down into the glens, and spreads itself out in the valley below. We have, then, here, in a pre-historic lava stream, older probably than the earliest day on which man walked upon the earth, exactly the same appearances—allowing for the changes wrought by time—as we can observe on the streams which have issued from an active volcano during the last few centuries.

Some of the smaller craters on the side of Vesuvius can hardly be said to have cones. They are little more than "blow-holes," from which gases have been discharged in successive explosions, from a molten mass below, ejecting very small quantities of scoria—just enough to form a hardly-perceptible ring around the orifice, and at last to close the aperture, so that it appears only as a bowl-like hollow in the flank of the mountain, lined within with scoria. Such a crater may be seen at no great distance from the Puy Pariou, on the side of the Puy de Dôme. It is called, owing to its remarkable shape, the Nid de la Poule, or "Hen's Nest." Now it is mostly overgrown with grass, and the cattle at pasture have trodden down tracks upon the slopes so curiously regular as to look something like the seats in an amphitheatre, or the contour lines on a map.

If now we transfer ourselves to a spot a few miles south of the Puy de Dôme, we find two cones of singular aspect, called the Puy de la Vache and the Puy de la Solas (Fig. 1). Each, though rising to a considerable elevation above its base, is imperfect. Each one has a wide opening on the same side, from which issues a stream of lava. On examining them we find them almost wholly composed of loose scoria, of a reddish colour, piled layer upon layer, showing that the whole cone has been built up in rudely-concentric coats or shells, as shower after shower of scoria and dust has been shot up into the sky by successive explosions, and has fallen like a stony hail round about the orifice of the vent. But what, it may be asked, has breached these craters? On examining them closely, it hardly seems as if we had here another instance of a destruction like that of Somma; all that remains is so perfect, and the openings have so close a resemblance one to the other. When we descend into the craters, and examine their inner slopes, we see here and there adherent craglets and patches of lava in considerable quantities. Some of these may be flakes, as it were, of stony scum, spurted up from the molten mass beneath; others, however, seem to extend too far horizontally, to be thus formed, and to be more like scum-rings left on the basin by a liquid.

In the following way, probably, the breach was made. The cones were evidently built of scoria only, and were raised to their present height before the lava issued from the vent. Then this welled up in the bottom of the crater, and rose—as it has been known to do in volcanoes still active—to some height within the walls. These at last—weakened, possibly, by the molten matter which was percolating through the scoria, and perhaps melting down some of the fragments—could no longer sustain the pressure from within; they gave way, on the side nearest the lower ground, and the lava streams poured forth. Whether the breaking down was nearly simultaneous in the two cones we cannot say, probably it occurred in both cases during the same eruption; for the two streams appear before long to merge themselves together.

There are places also in this district where the

under part of a lava stream may be seen no less plainly than the upper. The brooks have re-excavated their channels, the stone has been quarried, or some other cause has given us a section. One of the most interesting of these is in a cutting on the road, a mile or so south of Clermont Ferrand. Here a lava stream has flowed over cream-coloured marls, with an occasional stony band. On these it rests with a most irregular base, rising and falling some fifteen feet in about thirty yards, crushing and crumpling the softer beds, thrusting into them tongues and little veins, and entangling fragments of them in its mass. The marl has been baked by the heat, though for no great distance, and is changed for a space varying from a few inches to a yard, to a brick-red colour. The lava has a rough slaggy crust at its base, in thickness from one to six inches, after which it passes quickly into a dark compact rock, cut by irregular curving joints. Here and there it becomes suddenly scoriaceous, looking as if in rolling along it had enveloped fragments of its own crust, which after solidifying and resisting for a while, had ultimately given way to the pressure of the still liquid mass behind.

Besides the above examples, types only of numerous instances, we find cones and lava streams which have been more injured by the attacks of time. But, as in this region we find all gradations, from the ruin to the complete structure, we are able to interpret the less by the more perfect; and as the last bear the closest possible resemblance to the cones and craters of volcanoes still in activity, we obtain a clue which we can apply to the more obscure volcanic remains of a more remote past.

CELESTIAL OBJECTS VIEWED WITH THE NAKED EYE.

By W. F. Denning, F.R.A.S.

THERE are many persons possessing a love for scientific subjects who relinquish all idea of ever doing any useful work because they have not the means to procure expensive and elaborate instruments. They imagine that in order to cope with their contemporaries it is necessary to be similarly provided with the best appliances for observation and experiment, and a well-stocked library of new and standard works for reference. This is particularly the case in astronomy. A man thinks, when his attention is first attracted to the subject, that the colossal telescopes existing in observatories in various parts of the world have already made all the possible discoveries, and that a puny, indifferent instrument such as his own is incapable of displaying anything new or revealing much of what is previously known. He begins to despair, and when he has seen a few of the chief objects dimly portrayed in his small glass becomes dissatisfied, and ultimately it is laid aside as his thoughts enter a new groove, for he takes up a different hobby holding out a better chance of success and pleasure. This has been the case many times, and will be so again; but there is no need to say that a person may accomplish very useful work by the proper application of the means at his disposal, and that even without any instruments at all there is a large amount of valuable astronomical data to be collected and many sights to be seen that shall fill the spectator with genuine interest. In fact, there are many celestial appearances which are only observable with the naked eye, for they will not admit of examination in the contracted field of a telescope. The chief thing necessary to success is a great love for the subject, for this is required to sustain the enthusiast through his nightly vigils, and will lead him to devise the means by which his ends may be best attained, and will point him to the particular department in which he is likely to achieve something useful. Unremunerative labour tires most men, but the true student of science will make any sacrifice of time and labour in the development of his observations or theories. Not that a man need necessarily let his scientific work interfere materially with his business avocations. In the evening, after the day's toil, rest may be found in the contemplation of celestial objects, and when the subject is pursued in moderation it tranquillises and elevates the mind, and affords a welcome relaxation and change. And such observations, while thus proving beneficial, may become of real value to science if the observer records a careful and accurate account of what is displayed before him. Eclipses of the sun and moon, apparitions of the aurora borealis and zodiacal light, variable stars, shooting stars, comets, and many

other objects and phenomena come within range of the unassisted vision, and require much further watching and description. To such observations as these, extending over a long period of years, Professor Heis almost entirely owed his great reputation as an astronomer. Telescopes he might have used, and of the first excellence, had he wished, but he preferred to rely upon his eye alone; and his extensive publications, embracing star atlases and catalogues, the paths of many thousands of shooting stars, observations of the zodiacal light, &c., are a sufficient testimony of his unwearying energy, and an incentive to less ardent students in the same field. It is true that instruments are so much improved, and have multiplied to such an extent during the last few years, that an astronomer without a telescope would be deemed quite a curiosity at the present day; but it is certain that, however much optical aid is necessary for some kinds of observation, it is possible to discern many natural beauties with nature's own unaided vision, and thus to gather many new facts from the rich stores of space.

The discoveries made by the ancients long before the invention of the telescope show that they must have been very keen-sighted and diligent in observation. The planet Mercury, so rarely to be seen, must have eluded detection for a considerable period. Immersed in the mists and clouds of the horizon, and visible only for a very short interval at a time, he would be certain to long escape the old observers as they eagerly scanned the heavens in search of new orbs. When once seen, however, and when the position was found not to be reconciled with that of any brilliant fixed star, the truth must soon have been suggested to the observer. With what pleasure must he have awaited the next fine evening to verify his discovery, and with what zeal must he have again recorded its apparent place, finding a slight difference due to the planet's motion, and thus setting at rest, at once and for ever, the true nature of the object he had been watching. Humboldt remarks that from the earliest times the Egyptians were occupied with the planet Mercury, and that under the clear sky of Western Arabia the star-worship of the tribe of the Asedites was directed exclusively to this planet. Ptolemy, in the ninth book of the "Almagest," was able to avail himself of fourteen observations of Mercury, extending back to 261 years before our era, and belonging in part to the Chaldeans. Thus, the old astronomers proved themselves to be observers of remarkable power. From their watch-towers they recorded the motions and phenomena of the celestial orbs and depicted the places of the stars. Many historical records of eclipses have been handed down to us, and in old chronicles one may find notices of large comets which generally inspired people with dread, for they were thought to be of malign import, bringing with them famine and disease. And it is not surprising that such objects were looked upon with terror at that time, when they were so little understood, for there is much in the apparition of a great comet to instil dread into the popular mind. The flaming train, the brilliant nucleus, the rapidity of motion, were calculated to fill ignorant observers with awe. It is different now, when so much has been learnt of the nature of these bodies, and we are come to regard them simply as multitudes (or streams) of shooting stars, incapable of harm or evil influence.

Coming down to more modern times, one of the most remarkable of naked eye observations was that by Moestlin (Preceptor of Kepler) of eleven, and perhaps fourteen, stars in the Pleiades, commonly called "the seven stars." To ordinary vision six stars only are visible, but the telescope has displayed a large number of fainter ones scattered amongst the group. On December 24, 1579 (nearly thirty years before the invention of the telescope), Moestlin determined the positions of eleven of them, and they are found to coincide with the points now more exactly ascertained. The writer has frequently looked at this well-known

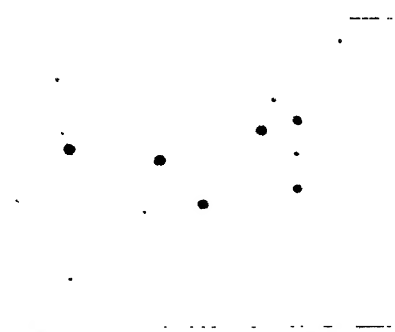

Fig. 1.—The Pleiades as seen by the Naked Eye, December 6th, 1876.

asterism, and finds thirteen stars usually visible to the naked eye. On the night of December 6, 1876, when the atmosphere was exceptionally transparent and the stars shining with remarkable brightness, fourteen were detected in the positions approximately assigned in the sketch (Fig. 1).

This group forms a specially interesting object, and is favourably visible throughout the autumn and winter months. The smaller stars are very faint, and the observer should remember that a minute object is often glimpsed by averted vision when steady, direct gazing fails. Anyone who cannot succeed in seeing these smaller stars of the

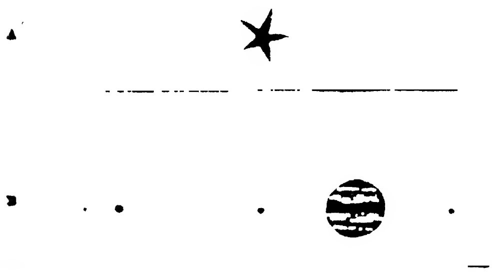

Fig. 2.—Jupiter as observed by the Naked Eye (A) and as observed in a Telescope (B).

Pleiades will have no chance in observing the satellites of Jupiter with the naked eye, for though they have been undoubtedly detected without telescopes, yet they are very faint, and being immersed in the planet's rays, are almost wholly overpowered, except at the time of greatest elongation, when two of them (the third and fourth) being occasionally in conjunction, afford a capital opportunity for testing the vision (Fig. 2). These little moons are generally in a line with each other, though not invariably all visible, for they suffer numerous eclipses and allied phenomena. As to Jupiter himself, he is often perceptible in daylight. Bond has often seen him with the naked eye in high and clear sunshine, and the writer has observed the planet several times half an hour after sunrise. Venus is always a very conspicuous object in the daytime, when her position is sufficiently distant from the sun. The writer has frequently seen this planet at noon, shining very strongly, and she has been similarly noticed by many people. In fact, there is no difficulty whatever in seeing this beautiful planet in the daytime, if the position is pretty well known, and care is taken to make the observation from a place where the sun's direct rays are intercepted and cannot dazzle the eye.

Another object of some interest to naked eye observers is the middle star (ζ) in the tail of Ursa Major, which has a small companion, named Alcor, close to it. It was called "Saidak" by the Arabs, signifying "the Tester," for it was customary amongst them to test a man's power of sight by it. Humboldt, in his "Kosmos," says that he has seen the smaller star with great distinctness every evening on the rainless coast of Cumana, but has recognised it only rarely and uncertainly in Europe. Observers may, however, find no difficulty in seeing the star, for it is a remarkably easy object, and, at the present time, certainly no test of vision. It may possibly have become brighter than it formerly was, for it is now extremely plain, even in unfavourable conditions of the atmosphere. There is a third and fainter star near it which really forms a very difficult object to reach with the naked eye.

There are some stars, affording good examples of proximity (though differing little in magnitude), which require care in separating them without resorting to instrumental aid. The chief star (Alpha) in Capricornus consists of two stars of the third and fourth magnitudes, about six and a quarter minutes of arc asunder (corresponding to one-fifth of the moon's diameter), and readily distinguished as a double star. Epsilon Lyræ presents another (though more difficult) instance of like nature.

The sun and his dark spots offer another object of attraction, though it cannot be denied that a telescope possesses a great advantage in such work. The spots were first seen, however, many centuries

Fig. 3.—Sunspot, May 6th, 1871: 2.30 p.m. Telescopic View (A); Sunspot, May 7th, 1871: 11.30 a.m. Telescopic View (B).

before that instrument came into use. They appear, on the sun in large numbers, and often of considerable size, at intervals of about eleven years, when they are frequently perceived by the naked eye. On March 31, 1870, the writer saw four large spots on the sun just before his setting, when the haze on the horizon allowed his disc to be

conveniently scanned. There were many spots upon the sun about that period; and one observer, who detected them with no other help than coloured glass to shield his eye, describes them as forming two parallel bands across the sun, one on either side of his equator. There was a fine spot visible on the sun in May, 1871, which in a good glass exhibited some interesting details (Fig. 3). When the sun's light is partially obscured by fog, as it often is at rising and setting, a spot may often be discerned; and during the next few years we shall find many such instances, for the time of maximum intensity of these phenomena will soon be approaching.

The full moon as she rises is one of the grandest of celestial sights. At the time of harvest, when she comes above the horizon at about the same hour on several successive nights she is best seen. The dark irregular outlines of her plains may be readily distinguished, and perhaps a faint indication of some other features. It is a very interesting point to see how soon after conjunction (*i.e.*, new moon) she may be observed. At 9 p.m. on June 4, 1875, the writer saw the moon when less than twenty-three hours old, and visible as a very slender crescent indeed. In the spring months an observer may sometimes catch the young moon as early as this, but only when the sky is very clear. An instance is recorded of the moon's thin crescent being seen early one morning before sunrise and after sunset on the following day, and in the torrid zone Vespucius is said to have seen her east and west of the sun on the same day.

The near approach of planets and bright stars (such as Aldebaran in Taurus, or Antares in Scorpio) to the moon are well observable by the naked eye. So are conjunctions of planets and similar occurrences, which are always notified in almanacks, from which we may easily find when and where to look for them.

Of the planets Mercury is the most unique object. He was designated "the strongly sparkling" (στίλβων) by the Greeks on account of his occasional intense light. The planet is alternately in view as a morning and evening star, when at greatest elongation west or east from the sun, and at such times he may be generally seen near the horizon, though Copernicus, who lived to attain his seventieth year, complained on his death-bed that he had never seen him. In May, 1875, he was observed by the writer on thirteen evenings. The planet's light varies, however, on successive nights, owing to the rapid difference in phase and distance from the earth.

Uranus is visible to eyes of ordinary power, but is liable, from his faintness, to be confused with small stars lying near his path. The exact position he occupies should be found from an ephemeris, and marked on a reliable star map, then comparing it with the sky, the planet may be recognised, and if the observations are continued for several weeks a slight change will have occurred in his place, and thus his identity will be beyond question.

But the several objects to which we have been referring are mere interesting tests for the eye, from which the observer may often gather some pleasure, though it can hardly be said that such work can benefit science. It is in other departments that the amateur should chiefly confine his energies, and to these we may now briefly turn.

Eclipses, though best observable in telescopes, present phenomena properly within reach of the naked eye. The gathering darkness as the eclipse increases, its intensity and effects upon the sky and

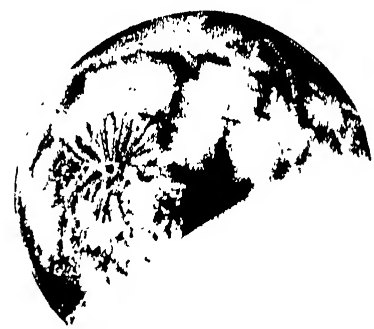

Fig. 4.—Partial Lunar Eclipse as observed in a small Glass.

landscape, are very imposing to one who witnesses the spectacle for the first time, and the impression it gives is perhaps never forgotten. In eclipses of the moon the intensity and colouring of the earth's shadow, as observed projected upon our satellite, vary a good deal in different eclipses, and it should be the aim of observers to note these peculiarities. At totality the moon's surface still remains visible, with the chief outline of her more prominent features, though instances have been recorded in which the moon's face has been wholly obscured, for the density and extent of colouring on the overshadowed moon depend in great measure upon the condition of the earth's atmosphere, through

which the sun's rays are transmitted to her surface (Fig. 4).

Variable stars, and those suspected variable in light, should be often examined and their relative brightness recorded. In the case of the more conspicuous stars no glass is required. The important fact to ascertain in connection with variable stars is their periods of greatest and least brilliancy, and this is best found by frequent estimations of the comparative lustre of the stars. It is a good plan to compare two adjoining stars (differing little in magnitude), and, glancing back from one to the other several times, determine their relative brilliancy. Argelander has adopted a convenient method of denoting the results by "steps" or gradations of light. Thus if two stars, *a* and *b*, are exactly equal, then we may write *ab* or *ba*, which indicates equality, but if on attentive comparison *a* is found just perceptibly the brighter of the two, then *a* 1 *b* signifies the difference. If *a* appears decidedly the brighter star, then write *a* 2 *b*, and so on up to four steps, beyond which it is not considered practical to estimate with any certainty.

Shooting stars* are especially within the province of the amateur. Every fine night when the moon is absent the sky should be watched, and their apparent paths among the stars registered. Many different meteor showers are in activity every day, and it is to determine the positions of these that further watching is required on the part of observers. They may be found by noting the visible directions of the meteors and projecting their apparent paths upon a star chart, when it will be discovered that they have several points of convergence or intersection in the same backward line of motion. The valuable facts to ascertain in connection with meteors are the accurate centres of these radiant points, and there appear to be vast numbers of them.

The "Northern Lights,"† though only an occasional phenomenon, should be carefully looked for on clear nights. There are many varieties of these apparitions, and even during the same display the form undergoes rapid and striking modifications. Sometimes we see an array of streamers fringing the northern horizon and stretching upwards to different altitudes. Sometimes a coronal arch spans the heavens in that direction, and sometimes the whole sky there is suffused with an intense glow, and there are marked condensations of light in various quarters. But under whatever form the phenomenon is perceptible, if it is watched long it will be seen to assume new aspects, and it is for the observer to carefully note these as they succeed each other. The intensity and positions of the streamers, with their durations and altitudes, and other similar details that will suggest themselves, must be faithfully recorded, so that in future displays the facts may be compared and utilised by those who would deal theoretically with these remarkable exhibitions.

The zodiacal light should also be made an object of investigation whenever the weather is clear. It is generally more intense in the evenings of March and mornings of October than at other seasons of the year. This year (1879) it was also very bright on several evenings at the end of January. Its comparative intensity at different times of the year should be made the subject of much further inquiry. The altitude and place to which the sloping cone of light ascends should be always estimated with care.

Comets are not often large enough to be seen by the naked eye, but when one of these objects makes its appearance it may be conveniently followed night after night as it passes through the constellations. The form and length of the tail may be approximately ascertained by comparison with stars, and the general picture will possess more attraction than can be afforded telescopically, for the view will be of greater extent and variety.

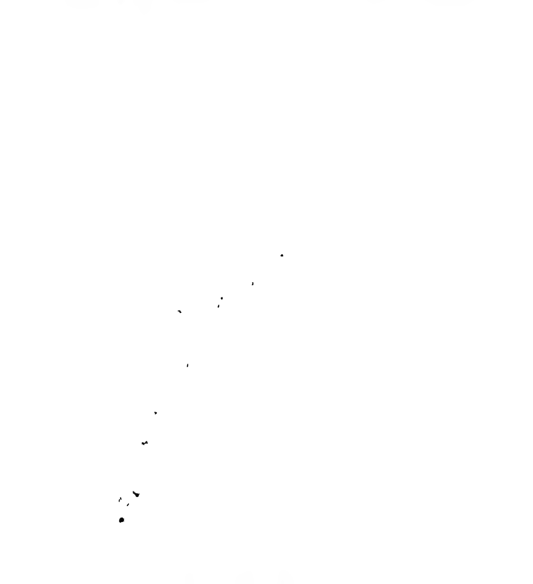

Fig. 5.—The Great Comet of 1858 passing the Star Arcturus, on October 5th.

* "Science for All," Vol. II., p. 144, *et seqq.*

† "Science for All," Vol. II., p. 1, *et seqq.*

Sometimes an opera-glass is a very valuable adjunct in observations such as these, and in the absence of a telescope will often prove a most efficient substitute.

A most unique spectacle for the naked eye was presented by Donati's large comet on October 5, 1858 (Fig. 5), as it crossed over the brilliant star Arcturus.

In addition to the objects and phenomena here severally referred to as affording interesting work for the unassisted eye, there are many others, some of which will come before the observer as he explores the sky. The scintillation of the stars at different altitudes, the colours of the stars, the occurrence of solar and lunar halos, &c., may also be mentioned as likely to attract notice, though the latter are meteorological phenomena depending on the condition of the atmosphere, which, in fact, gives rise to many such appearances. It is very unfortunate that clouded skies so often baffle the observer, and that in this climate we do not often obtain a really favourable view of celestial objects. Thus many occurrences of rarity pass unrecorded. It is seldom that anything near the horizon can be well seen, for mist and smoke congregate at low altitudes and intercept the clearness of the view, though celestial objects look very conspicuous when low down, much more so, indeed, than when near the zenith. Disappointment is one of the frequent experiences of the astronomer, but it often proves an incentive to increased vigour and watchfulness. We know that difficulties often intensify ardour, and here, in the wide domain of astronomical science, there are many attractive difficulties, many problems to solve, and many alluring wonders to be seen by aid of the least costly instruments, and even by the naked eye alone.

THE COLOUR OF THE SEA.

BY JOHN JAMES WILD, PH.D., F.R.G.S.,

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AN inquiry into a subject so familiar to everyone as the appearance, and more especially the colour, of the sea, seems at first sight to promise little that may prove to be either new, interesting, or useful. Ever since poet indited verse in praise of the "deep blue sea," or painter took up the brush in order to portray the glories of the "azure main," it has been settled for us and for all time that the sea is blue, and such expressions as the "blue deep," and the "blue ocean" have become stereotyped phrases in the vocabulary of our language. Yet the fact that the waters of the sea sometimes appear, and very often are of a different colour, forces itself on the attention of even the most superficial observer. As we take our stand upon the shore, the waves, which in the distance are of a dark blue tint, assume on nearer approach a more greenish hue, until at last, laden with particles of sand, or mud, stirred up by their own commotion, they break at our feet a yellow or brown mass of water. Or if, from some tall cliff, we look down upon the sea, the latter often appears divided into light and dark coloured patches, an appearance which we are at once tempted to ascribe to the nature of the sea-bottom, here composed of white or yellow sands, there of dark rock, covered with sea-weeds. A glance at the map of the world, where we find such names as the "Red Sea," the "Yellow Sea," the "Black Sea," the "White Sea," also shows that other colours besides blue have attracted the attention, and impressed themselves upon the memory of the early navigators of these seas, although in some of the instances just quoted, the name probably had its origin, not in the actual colour of the water, but in the aspect of the surrounding land, such for example as the gloomy and inhospitable-looking coasts of the Black Sea, and the snow-clad, ice-fringed shores of the White Sea. Again, the manner in which the sea surface reflects the varying hues of the day, from the pearly grey of dawn to the crimson and gold of sunset, or changes its tints according to the state of the weather, from cerulean blue to an inky black, is well known to all dwellers by the sea-side. However, it is not with these transient and readily explained effects of illumination that we intend to deal at present, but rather with the causes which determine the actual colour of the sea-water, as exhibited with more or less permanency in different parts of the ocean.

The changes in the colour of the sea have attracted the attention of seafaring men from the earliest times. They struck with wonder the Phœnicians when first they ventured out of the

Mediterranean into the Atlantic; they excited the astonishment of Columbus and terrified his companions, while in search of the far-famed Indies; and they are no less a surprise to the modern navigator, to whom the march of discovery has left few unexplored regions in store.

Numerous theories were offered in explanation of these changes, some ascribing them to the varying colour of the sea-bottom, some to differences in depth, others to the presence of certain colouring substances, others, again, to the chemical composition of the water. Most of these suggestions contained an element of truth, although no one of them, taken by itself, sufficed to account for alterations in colour which had often been observed to occur in the course of a few hours' sail, and within a distance measuring less than a ship's length. Of late years, as the reader is aware, numerous scientific expeditions have been fitted out and despatched by the Governments of England, Norway, Germany, and America for the express purpose of exploring the secrets of the deep. Among the problems which have now, for the first time, received a satisfactory solution, new light has also been thrown upon the conditions which affect the colour of the sea-water in every part of the ocean; thus completing the information for which we were indebted to the unaided exertions of earlier travellers.

One of the most remarkable, and most widely distributed contrasts of colour, is that which is known to exist between the intensely blue seas situated between the tropics and the green seas of higher latitudes. It appears, as the result of recent observations, and more especially of a series of experiments made on board the German frigate *Gazelle*, that there is an intimate relation between the colour of sea-water, and the proportion of salt held in solution by the latter. On comparing the specific gravity of green water with that of blue water, it was found that the latter is always heavier than the former, and, therefore, at the same time more salt, the two differently coloured waters being supposed to have the same temperature. In other words, the greater or lesser intensity of the blue colour of sea-water may be taken as a direct index of its saltness, and of its specific gravity, so that when we observe the colour of the water successively change from a deep blue to a bluish green and a dark green, we may conclude that the water has become at the same time less salt, and less heavy. This result agrees with the experience of navigators in every part of the ocean, for, as the vessel proceeds from the dense and salt waters of the tropical regions towards the lighter and fresher waters of higher latitudes, and of the polar regions, the colour of the sea is seen to change from an intense blue to a greenish blue, and green tint. There are, however, numerous exceptions. Green seas are met with between the tropics, and blue seas are encountered in the temperate region, and even within the Arctic circle, but these exceptions, as will presently appear, far from contradicting, only tend to confirm the above rule.

During the cruise of H.M.S. *Challenger* from the Canaries to the Cape de Verde Islands, when the ship was about half-way between the two groups and at a distance of about five hundred miles to the north-west of the mouth of the river Senegal, the water of the sea was observed to change from a blue to a green colour, and to retain the latter colour for the next following days, so that this green water must have covered a considerable area between the two island groups. A similar change of colour, accompanied by a decrease in the specific gravity of the water, was recorded by the officers on board the *Gazelle* on her voyage from Ascension Island to the mouth of the river Congo. Already at a distance of 900 miles from the African coast the colour of the water was seen to pass from dark blue to a bluish green. Two days afterwards it became again blue, but on the third day the water assumed a dark green tint, which gradually turned into a dirty green, until at a distance of more than 200 miles from the mouth of the Congo, the ship entered the brown waters which that mighty river carries down to the sea. All these changes of colour were accompanied by a corresponding change in the specific gravity of the water, which was found to increase as the water became more blue, and to decrease as the colour changed to green and finally to a brown tint. There can be little doubt that those wide areas of green water discovered by the *Gazelle* and the *Challenger* off the mouth of the Congo and the Senegal are due to the immense volumes of fresh water constantly poured into the sea by these great African rivers. The fresh river water, on account of its inferior specific gravity, will float on the top of the heavier salt water of the ocean, and, as we may safely conclude from the above observations, it continues to float thus for a considerable time, and to a distance of several hundred miles from the mouth of a large river. A convincing proof of the difference in colour between river water and sea water, and of the fact that the former floats and spreads out on the top of the latter, was furnished

by a remarkable sight witnessed on board the *Gazelle* both on entering and leaving the mouth of the Congo. The action of the ship's screw was observed to bring up the sea water from below to the surface, which thus formed a dark green track in the wake of the ship, while the brown waters of the Congo continued to flow on both sides of the track, and soon after were seen to close in once more over the green water. Occurrences of a similar kind have probably been noticed at the mouths of other great rivers, but they have not been studied with the attention they deserve. From experiments made to test the transparency of sea water, it would also seem that the proportion of salt contained in the latter considerably affects the depth to which an object lowered into the sea remains visible to the naked eye. For example, a white tin sent down into blue, that is to say, very salt water, remained visible at a depth of fifteen feet, while in green or fresher water, it disappeared at a depth of only eight feet.

Just as green water may be met with between the tropics contrasting with the normally deep blue colour of the equatorial seas, so is water of an intense blue found outside the tropics, forming a not less remarkable contrast with the usually blue-green, or entirely green, waters of higher latitudes. A well-known instance of this is furnished by the Mediterranean. This sea, the deepest part of which—between the islands of Malta and Crete—exceeds two miles, forms a deep basin only communicating with the Atlantic Ocean by a narrow and comparatively shallow channel, the Straits of Gibraltar. Exposed to the rays of a meridional sun, while at the same time the supply of fresh water from rivers is insignificant when compared with the superficial area and the depth of this sea, the waters of the Mediterranean are condensed by evaporation, and are rendered more salt and heavier than the waters of the Atlantic outside, hence the beautiful, intense blue colour of this sea, which forms so important a feature in the coast scenery of that region.

The Gulf-stream current supplies another example of the occurrence of deep blue water outside the tropics. This powerful current, as it issues from the Straits of Florida, pours the warm and intensely blue waters which it has gathered during its progress through inter-tropical seas, into the North Atlantic. As it flows towards the north and north-east, the Gulf-stream comes in collision with the Arctic current, also known as the Labrador current, and which runs in the opposite direction. In consequence of this encounter, the portion of the Atlantic between the Bermuda Islands and the Banks of Newfoundland is divided into broad, sharply defined streaks of alternately green and blue water, green where the Arctic current rises to the surface, blue where the Gulf-stream current is seen to pursue its way towards the western shores of Europe. Even inside the Arctic circle, near Spitzbergen, and off the west coast of Greenland, navigators have been able to trace and to identify by its blue colour the water carried into the Arctic regions by currents from the south, and thus to distinguish it from the green polar water by which it is surrounded.

Thus it is evident that an attentive observation of the colour of the sea may lead to conclusions interesting and useful not only to the scientific inquirer, but also to those hardy men who earn their living upon the waters. Both the fishermen on the coast and the mariner upon the high seas take note of the colour of the water as affording trustworthy indications of the vicinity of land, or of the mouth of a river, the depth of the water, the presence of a current, &c. When the mariner finds himself lost in a fog, or when the sky has for days been covered with clouds, so as to prevent the taking of observations, the colour of the sea may give him a clue as to his whereabouts, and often by this means he has been able to save both himself and the property entrusted to him from imminent destruction. On the other hand the scientific traveller may use the colour of the water as a trustworthy index of its saltness and specific gravity, or as a guide in following the track of those great oceanic currents which flow from the Equator to the Poles, and return thence as cooling streams to temper the heat of the Torrid Zone.

The varying tints of blue and green, however, were not the colours which most attracted the attention and excited the astonishment of the adventurous navigators, who boldly steered their course towards distant and hitherto unknown seas. Picture their surprise and even dismay when they suddenly found themselves in sight of, or sailing in the midst of wide tracts of water of a red, or yellow, or brown, or dark inky colour! Oftentimes they discovered, upon nearer inspection, that this strange appearance was due to vast masses of floating seaweed, now linked together so as to form long coloured streaks extending as far as the eye could reach, now congregated in wide patches like so many floating islands. These seaweeds or aquatic plants form, as the reader is aware. an important sub-division of the vegetable kingdom,

and are classed by the botanist under the name of *Algæ*. They abound largely both in salt water and in fresh water, but of marine species alone more than 6,000 have been described up to the present. These algæ include some of the largest plants in existence as well as the most minute, visible only by the aid of the microscope. Gigantic algæ occur in the greatest abundance in the vicinity of the islands of the Southern Ocean, more especially Kerguelen's Land, the Heard or MacDonald Islands, Prince Edward Islands, Tristan da Cunha, and the Falkland Islands. The largest among them is *Macrocystis pyrifera*, which congregates in masses that from a distance look like meadows. Many specimens of this plant have been seen measuring 300 feet in length, and some even extending to 700 feet. Another large, brown-coloured species has been named *D'Urvillaea utilis*. The latter when rolled by the surf on the beach forms enormous cables several hundred feet long, and as thick as the human body. Such cables washed off by storms and carried out to sea are suspected to have given rise to the story of the far-famed, but as yet undiscovered sea-serpent. Many seaweeds are found attached to rocks by root-like processes which enable them to sway about in the water. To these belong the well-known tangles—*Laminaria*—of our own sea-coast. Other seaweeds are always found floating. Such is the case with the celebrated Gulf-weed — *Sargassum bacciferum* — a characteristic and striking feature of the central portion of the North Atlantic, hence named the *Sargasso Sea*, from the Spanish word *Sargazo*, meaning seaweed. It presents the appearance of yellow, feathery bunches, sometimes swimming separately on the surface of the sea, but more frequently congregating in wide patches and streaks extending as far as the horizon. These bright yellow patches, divided from each other by a labyrinth of deep blue lanes, when lighted up by the almost permanent sunshine of these latitudes, offer one of the most extraordinary and not readily forgotten sights witnessed by the traveller on the ocean. It is these floating meadows which seemed to have inspired the companions of Columbus with dismal forebodings, as we find recorded in the accounts of their first voyage across the Atlantic. To their superstitious minds the ocean appeared to have been converted, through the influence of malign powers, into an endless tangle of a mysterious vegetation, spreading far and wide, and threatening to arrest the ship in its course.

When, as in the instances above mentioned, the abnormal colour of the sea proved on nearer inspection to be caused by vast accumulations of seaweed floating on and near the surface of the sea, the explanation of these unusual appearances presented no difficulty whatever. But from the earliest days of ocean navigation, large patches and extensive areas of discoloured sea-water have been traversed by ships in different parts of the ocean, more especially in the cold seas of the Arctic and Antarctic regions, where even on the closest inspection there was no trace of seaweeds or other vegetable or animal organisms visible to the naked eye, sufficient to account for the change in the colour of the sea, and for a long time the phenomenon remained a mystery, a fertile source of more or less absurd conjectures. For example, in their attempt to explain the origin of the name of the Red Sea, ancient writers speak of mountains which cast a red reflection on the sea—of red sand—of divers bringing up a red substance resembling coral, &c.

The veteran navigator, John Davis, in the account of his first voyage in June, 1585, to the strait which now bears his name, remarks that in the strait "the water was very blacke and thicke, like unto a filthy standing pool." Captain Scoresby, during his numerous whaling expeditions in the Arctic Sea came to the conclusion that this discoloured water formed perhaps one-fourth part of the sea surface between the parallels of 74° and 80° north latitude. "Sometimes," he says, "I have seen it extend two or three degrees of latitude in length and from a few miles to ten or fifteen leagues in breadth. It occurs very commonly about the meridian of London in high latitudes. In the year 1817 the sea was found to be of a blue colour and transparent all the way from 12° east, in the parallel of 74° or 75° north latitude to the longitude of 0° 13′ east in the same parallel. It then became green and less transparent; the colour was nearly *grass green*, with a shade of black. Sometimes the transition between the green and blue waters is progressive, passing through the intermediate in the space of three or four leagues; in others it is so sudden that the line of separation is seen like the rippling of a current; and the two qualities of the water keep apparently as distinct as the waters of a large muddy river on first entering the sea." A more recent voyager in the Arctic Seas, Dr. Robert Brown, to whom we are indebted for the first satisfactory explanation of the true cause of this discoloration — and his observations have

been confirmed by Koldeway, Nordenskjöld, and Nares—states: "I have often observed the vessel in the space of a few hours, or even in shorter periods of time, sail through alternate patches of deep black, green, and cerulean blue; and at other times, especially in the upper reaches of Davis Strait and Baffin's Bay, it has ploughed its way for fifty or even a hundred miles through an almost uninterrupted space of the former colour. The opacity of the water is in some places so great that 'tongues' of ice and other objects cannot be seen a few feet beneath the surface." Professor Nordenskjöld, the intrepid Arctic explorer, referring to Dr. Brown's previous observations, makes the following remarks on the colour of the Arctic Seas: "The sea-water in the neighbourhood of Spitzbergen is marked by two sharply distinguished colours—greyish-green and fine indigo-blue. In the Greenland Seas we also find water with a very decided shade of brown. These colours are seen most pure if one looks vertically down from the ship to the surface of the water through a somewhat long pipe. The green, or rather grey-green, water is generally met with in the neighbourhood of ice (whence it was supposed to arise from the Arctic current); the blue, where the water is free from ice; the brown, as far as I am aware, chiefly in that part of Davis Strait which is situated in front of Fiskernaes. When specimens of the water are taken up in an uncoloured glass, it appears perfectly clear and colourless, nor can one with the naked eye discover any organisms to account for the colour. But if, when the velocity of the ship allows of it (*i.e.*, when the ship makes from one to three knots an hour), a fine insect net be towed behind the ship, in the green and brown water, it will soon be found covered with a film of—in the former case green, in the latter case brown, slime, of organic origin, and evidently the real cause of the abnormal colour of the sea-water." Another fact, well known to whalers, is that these patches of discoloured water are frequented by vast swarms of minute animals which form the principal food of the great "Right Whale" of commerce—*Balæna mysticetus.* Accordingly the "black water" is eagerly sought for by the whaler, knowing that since it swarms with the food of their chase, they are more likely to find the animal itself. These small animals—chiefly Medusæ, Crustaceans, Pteropods, and many other lower forms of animal life—were at first supposed to be the cause of the abnormal colour of the sea-water, but when, owing to a change in the weather or for some other reason, these organisms disappeared from the surface of the sea, it was observed that the water still retained its peculiar colour, and hence the real cause of the discoloration had to be looked for elsewhere.

Dr. Robert Brown, during his voyage in 1861 to the seas in the vicinity of Spitzbergen, and subsequently to Davis Strait and Baffin's Bay, submitted specimens of this discoloured water to a careful examination under the microscope. He found that not only does this water swarm with small animal organisms as had been noticed by previous observers, but that it contained at the same time immense numbers of still more minute objects which he identified as being *Diatoms*, microscopic organisms for a long time considered by the highest scientific authorities as animals, but now included in the vegetable kingdom and classified with the *Monocellular Algæ.* These minute vegetables, taken separately, are invisible to the naked eye, but when gathered together in thousands and hundreds of thousands, they assume the appearance of a thin film or slime of a yellow, or green, or red, or most frequently of a brown colour. Diffused in water in numbers which transcend the bounds of human imagination, they undoubtedly are the cause of the abnormal colour of the sea-water so frequently observed in different parts of the ocean.

The *Diatomaceæ*, so called from a Greek word which means a cutting through, a division or separation, consists of a soft, variously coloured, granular, living matter enclosed in a hard, transparent, siliceous covering. The latter is composed of two valves which fit into each other by means of an upright rim projecting all round the edge of each valve. Their form varies with the different species, some being circular, others oval-shaped, some straight or linear like infinitely small rods, others are bent in the form of a crescent. Some widely distributed species are oblong, thickest in the middle and tapering off towards each end and hence have been named *Naviculæ, i.e.*, little ships. (Figs. 1, 2). Perhaps the most surprising fact in connection with these minute denizens of the sea, and which at first sight seems conclusive as to their animal nature, is that they have been observed to possess a motion of their own. Some species are seen to move backwards and forwards, others dart through the water with great rapidity, describing a zig-zag course. The cause of this motion remains as yet a mystery. It will give an idea of the minute size of these organisms when we state that a specimen of more than average size measures about $\frac{1}{100}$ part of an inch. In some genera the Diatoms are

found separate, in others they are joined together, and form ribbon-like threads or minute zig-zag chains. The Diatom (probably *Melosira arctica*) first observed by Dr. Robert Brown in the dis-

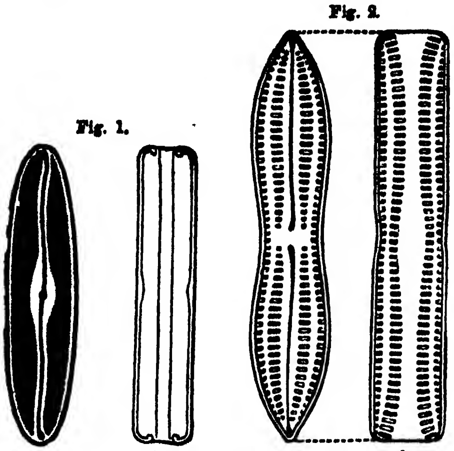


Fig. 1, Navicula liber; Fig. 2, Navicula Ægyptiaca; *a*, side view; *b*, front view. (*Magnified 400 times.*)

coloured Greenland water had the appearance of a minute beaded necklace about $\frac{1}{400}$ part of an inch in diameter, of which the articulations are about 1½ or 1¼ times as long as broad. These articulations contain a brownish-green granular matter, giving the colour to the whole plant, and again through it to the sea in which it is found so abundantly. These necklaces or filaments, when congregated in large numbers, compose a brown or yellow coloured slime, which has been observed to adhere to the ice in the Arctic and Antarctic regions. Quoting again from an interesting memoir by Dr. Brown on the discoloration of the Arctic Seas,"* the author remarks: "In June, 1861, whilst the iron-shod bows of the steamer I was on board of crashed their way through the breaking-up floes of Baffin's Bay, I observed that the ice thrown up on either side was streaked and discoloured brown; and on examining this discolouring matter I found that it was almost entirely composed of the siliceous moniliform Diatom I have described as forming the discolouring matter of the iceless parts of the Icy Sea. I subsequently made the same observations in Melville Bay, and in all other portions of Davis Strait and Baffin's Bay where circumstances admitted of it. During the long winter the Diatomaceæ had accumulated under the ice in such abundance that when disturbed by the pioneer prow of the early whalers they appeared like brown slimy bands in the sea, causing them to be mistaken more than once for the waving fronds of *Laminaria longicruris*, which is the common tangle of the Arctic Sea. On examining the under surface of the upturned masses of ice, I found the surface honeycombed, and in the base of these cavities vast accumulations of Diatomaceæ." During the cruise of the *Challenger* in the month of February, 1874, along the edge of the Antarctic pack-ice, the latter, as recorded by Mr. Henry N. Moseley,† was frequently stained of a yellow ochreous tint, caused by Diatoms washed up on to the ice by the waves, and hanging on its rough surface. This colouring was always most marked about the honeycombed wash-lines of the ice blocks.

Another most interesting discovery in connection with this subject, is the fact that the contents of the alimentary canals of the animals which in such immense numbers frequent the dark-stained waters of the polar seas, and which in their turn are the principal support of the huge whale, consist entirely of Diatoms. Thus the largest animal in creation, the pursuit of which gives employment to many thousand tons of shipping and thousands of seamen, depends for its subsistence on a being so minute that it takes thousands to be massed together before they are visible to the naked eye!

It was not till towards the end of the last century that the first known forms of Diatoms were discovered. The number of species at present ascertained to exist in the British Islands alone amounts to little less than a thousand. They are found both in salt water and in fresh water, in small streams and pools, covering the surface of the mud with a brownish film, or adhering to the stems and leaves of aquatic plants, or living on the face of moist rocks, in fact, in almost all places where there is moisture and light, the two conditions most essential to their growth. When they die, their hard, siliceous covering sinks to the bottom of the water in which they have lived, and there forms part of the sediment. In the course of ages this sediment becomes hardened into solid rock, and forms a substance well known in commerce and in the arts under the name of *tripoli*, a powder used for polishing stones and metals.‡ In this manner vast deposits of Diatomaceæ have been discovered in various parts of the world—some the

* "Admiralty Manual of the Natural History of Greenland" (1875); also *Das Ausland*, Feb. 27th, 1868, and Petermann's *Geographische Mittheilungen*, 1869, &c.

† In his valuable "Notes by a Naturalist on the *Challenger*."

‡ "Science for All," Vol. II., p. 277.

eposits of fresh water, others of salt water. Stony deposits mainly composed of the siliceous plates of Diatoms exist at Bilin in Bohemia, where a single stratum extending over a wide area, is no less than fourteen feet thick—also at Planitz in Saxony, on Isle of France or Mauritius, and at Richmond in Virginia. The latter deposit is remarkable for its extent as well as for the number and beauty of the species contained in it. It is said to spread over many miles, and to be in some places at least forty feet deep. Many of these species, the remains of which have thus been preserved during ages untold, are identical with species found living in our seas and fresh-water lakes of the present day. The illustrious Sir Charles Lyell, with reference to this subject, quotes the following line from Byron:

> "The dust we tread upon was once alive!"

and says:—"How faint an idea does this exclamation of the poet convey of the real wonders of nature, for here we discover proofs that the calcareous and siliceous dust of which hills are composed has not only been once alive, but almost every particle, albeit invisible to the naked eye, still retains the organic structure which, at periods of time incalculably remote, was impressed upon it by the powers of life."

While the *Diatomaceæ* play, as we have just seen, such an important part in the total discoloration of the Polar seas, another microscopic alga—*Trichodesmium*—is the cause of similar appearances in the warm seas of the tropical and sub-tropical regions. This minute vegetable organism is found covering large areas in the Red Sea, the Arabian Gulf, the Indian Ocean, the China Sea, and in the seas which wash the coasts of Australia, and of the American Continent. Its colour has been variously described as a bright red, yellowish-brown, or a reddish-brown. The red colour has been most frequently observed in the Red Sea, and it seems highly probable that we have here the true explanation of the name given to this sea from the remotest antiquity. The small sheaf-shaped bundles formed by this alga, when floating separately upon and near the surface of the water and lighted up by the sun, impart to the sea a sparkling appearance—as if the latter were impregnated with a luminous dust: hence the name of *sea-sawdust* given to it by Cook's sailors.

In Mr. Darwin's narrative of his voyage round the world, in H.M.S. *Beagle*, we find the following passage:—"When not far distant from the Abrolhos Islets, my attention was called to a reddish brown appearance in the sea. The whole surface of the water, as it appeared under a weak lens, seemed as if covered by chopped bits of hay with their ends jagged. Their numbers must be infinite; the ship passed through several bands of them, one of which was about ten yards wide, and, judging from the mud-like colour of the water, at least two and a half miles long."*

During the cruise of H.M.S. *Challenger*, this alga was met with in great abundance in the Arafura Sea, between Torres Straits and the Aru Islands. But according to Dr. C. Collingwood, who has given us an exact description of this interesting organism,† the China Sea appears to be the home of *Trichodesmium*. "Having left Singapore behind," he reports, "the appearance of sea-dust became an everyday occurrence in all its remarkable and interesting features. Nearly every day, while traversing this sea, more or less of it was to be seen, sometimes a mere sparkling appearance, while sometimes, and not unfrequently, the sea was

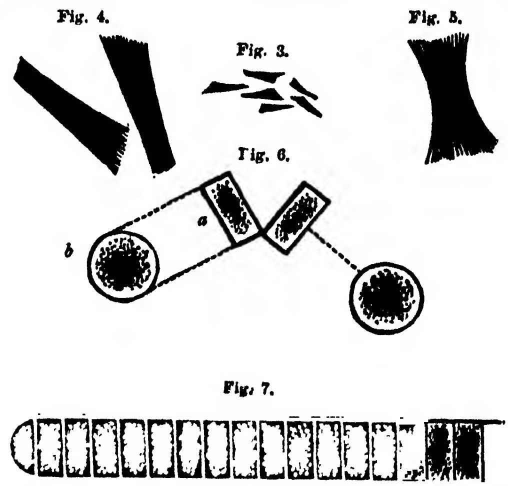


Fig. 3, Ordinary Wedge Form of *Trichodesmium* from the China Sea (*Natural size*); Fig. 4, the same, showing the Wedge-shaped bundles slightly magnified; Fig. 5, Sheaf-shaped *Trichodesmium*, from the Indian Ocean; Fig. 6, Single Cylindrical Cells in process of separation; a, side view; b, end view; Fig. 7, Single Filament composed of cells joined together, highly magnified.

covered with a thick scum of a yellowish-brown colour, like that which settles upon a stagnant pond." When seen by the naked eye, or slightly magnified, *Trichodesmium* presents the appearance of minute sheaves, or wedge-shaped bundles of fibres (Figs. 3,

* "Journal of Researches," by Charles Darwin, M.A., F.R.S., p. 14.

† "Observations on the Microscopic Alga which causes the Discoloration of the Sea in various parts of the World," by Dr. Cuthbert Collingwood, M.A., F.L.S.; "Transactions of the Royal Microscopical Society," Vol. XVI., 1868.

4, 5), hence its name, derived from the Greek, which means "hairy bundles." But when examined under the microscope, each bundle is seen to be composed of a "dense mass of cylindrical filaments

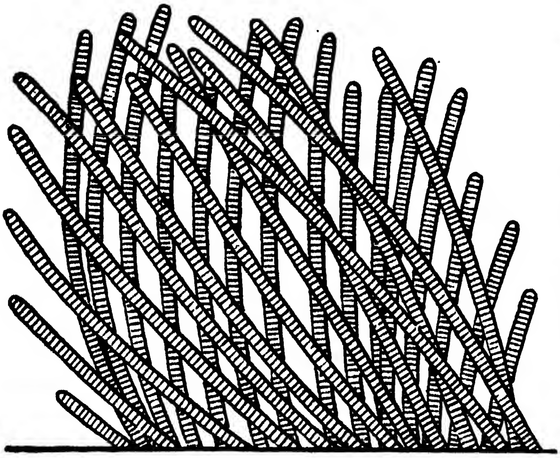


Fig. 8.—End of Sheaf or bundle of *Trichodesmium*, showing the loose filamentous structure, highly magnified. (*After Collingwood.*)

(Fig. 8) of unequal lengths, combined together, and interlacing with each other, forming an intricate network, having the appearance of a complicated basket-work, with the ends of the osiers sticking straight out as when the work is unfinished. Each filament is transversely divided by delicate lines, as distinct in character as the wall of the filament, each cell being seen to contain some granules of green matter in the interior, principally clustered about the centre (Figs. 6 and 7)."

Besides vegetable organisms, a variety of animals, some microscopic, others of larger size, are known to be a frequent cause of the abnormal colour of the sea. Returning to Mr. Darwin's interesting narrative, we find the following remarks :—

"On the coast of Chili, a few leagues north of Conception, the *Beagle* one day passed through great bands of muddy water, exactly like that of a swollen river; and again, a degree south of Valparaiso, when fifty miles from the land, the same appearance was still more extensive. Some of the water placed in a glass was of a pale reddish tint, and, examined under a microscope, was seen to swarm with minute animalculæ, darting about, and often exploding. They are exceedingly minute, and quite invisible to the naked eye, only covering a space equal to the square of one thousandth of an inch. Their numbers were infinite, for the smallest drop of water which I could remove contained very many. In one day we passed through two spaces of water thus stained, one of which alone must have extended over several square miles. What incalculable numbers of these microscopical animals! The colour of the water, as seen at some distance, was like that of a river which has flowed through a red clay district; but under the shade of the vessel's side it was quite as dark as chocolate.

"In the sea round Tierra del Fuego, and at no great distance from the land, I have seen narrow lines of water of a bright red colour, from the number of crustacea, which somewhat resemble in form large prawns. The sealers call them 'whale-food.' Whether whales feed on them I do not know; but terns, cormorants, and immense herds of great unwieldy seals, derive, on some parts of the coast, their chief sustenance from these swimming crabs."

The results of recent investigations into the causes of the colour of the sea, and of the apparent discoloration of the sea-water in certain areas of the ocean, may be summed up in the following words :—The various tints of blue and green which constitute what may be called the proper colour of sea-water, are due to a greater or lesser proportion of salt held in solution, the colour being an intense blue when the water is very salt, and changing by degrees to a green-blue, or blue-green, and green colour, as the water becomes more fresh. On the other hand, the abnormally coloured, red, yellow, brown, and inky seas owe their appearance to the accumulation of large masses of seaweeds, from the gigantic Algæ, which fringe the shores of oceanic islands, to the microscopic Diatoms; but almost as frequently the discoloration is caused by myriads of animal organisms collected in shoals at the surface of the ocean.

A discussion on the subject of the colour of the sea would be incomplete if we omitted mention of a phenomenon, perhaps more striking and more beautiful than any other aspect presented to the eye of the wanderer over the trackless ocean—we mean the phosphorescence of the sea. Who among the sea-loving inhabitants of these islands that has not passed, at some time or other, a quiet evening hour on the deck of a ship, or yacht, or sailing-boat, watching the luminous appearances which suddenly flash up from the dark depths of the sea, and, borne along by the invisible waves, finally disappear in the distance! At one time, these luminous displays take the shape of short bright flashes, and the sea seems dotted over with brilliant scintillating sparks. These are caused by a variety of small animals

chiefly crustacea. At other times we see large globes, filled with a weird, mysterious light, and which, phantom-like, rise and fall with the receding waves. These are due to the well-known Medusæ, or jelly-fish. Often—and this phenomenon seems to be confined to the seas of the warmer latitudes—the waves appear crested with a white luminous foam, which in the distance melts into one continuous sea of light, fairly eclipsing the quiet splendour of the starry sky. At such times the track of the ship looks like a long avenue of intense brightness, lighting up the sails and rigging. This magnificent display is produced by a microscopic animal, known to zoologists under the name of *Noctiluca*. Like the Diatoms, it abounds in myriads in the surface water of the sea, and, like them, its soft living matter is encased in a glassy transparent shell. But the most dazzling displays of phosphorescence are due to *Pyrosoma*, a jelly-like cylindrical mass measuring from two to ten inches in length, with a diameter of from one to two inches, and forming a colony of animals. These bodies congregate in immense luminous shoals, floating near the sea-surface, and sometimes embracing the whole of the visible horizon. When fished up from the sea, and touched with the fingers, they give out a bright bluish light at the point of contact, from whence the phosphorescence is seen to spread over the whole mass, as the shock or irritation rapidly passes from one animal to the other until the whole colony is in a blaze.

The phosphorescence of the sea is a conspicuous and almost permanent phenomenon in the bays and seaports of tropical and sub-tropical countries. There the shallow waters teem with an endless variety of small animal organisms, most of which are endowed with the faculty of giving out light. While hastening back to his floating home anchored in the offing, the belated mariner watches with wondering eyes the water as it falls from his oar, a liquid mass of silver and gold.

FLOWERING.

BY ROBERT BROWN, F.L.S., ETC.

IN an earlier part of this work,* when spring flowers were peeping above the half-thawed soil, we examined the anatomy of the Primrose. Since then the reader has had abundant opportunities of observing hundreds of other wild and cultivated flowers; and woods, and fields, and gardens have doubtless enabled him to confirm his early lessons in plant structure and functions, and to extend those he must have vaguely picked up for himself in dissecting the blossoms which have come in his way. Let us, however, begin where we last left off. We have seen how the flower is made up of certain essential organs, called stamens and pistils, and that on the action of these organs depends the formation of the seed. But if the observer has noted flowers with anything like attention, he must have observed certain phenomena connected with the act of flowering itself, which are of sufficient interest to deserve some discussion before we proceed to watch what follows after the flower has faded.

In the first place, it will be remarked that flowering is an exhaustive process, and that, as a rule, a plant flowers luxuriantly only when the foliage is kept in due subjection. A gardener prunes a shrub—and why? Simply because a great quantity of the nourishing sap† is required to support the flower, and as the roots can only take a certain amount from the soil, it follows that if this has to go to nourish the leaves and branches, the flower must starve, and as a result the plant will either not flower or produce puny blossoms. Hence, the gardener cuts off all superfluous wood, so far as he can do so without spoiling the beauty of the plant, if it be cultivated for ornament, or reduce the amount of fruit and flower-bearing superficies if the production of the latter is the aim of the cultivator. A gardener's common expression is that such a plant is "running all to leaf." He does not require to mention the antithesis of this, for his hearer will know well that it would be that it was not "running to" flower and the fruit and seed which follow. Take the example of maize or Indian corn. For its successful cultivation an average summer temperature of 65° Fahr. and a mean temperature two degrees higher in July, which is the ripening month, are required. In

* "Science for All," Vol. II., p. 215.

† "A Fallen Leaf," "Science for All," Vol. I., p. 19, and "How Plants Feed," p. 96.

southern climates the warm sun develops the juice of the corn too rapidly. Accordingly, it runs to leaf and stalk, to the neglect of the seed, or, as the botanist would say, the fruit, which constitutes the part for which the plant is cultivated. Then, in the West Indies, it rises as high as 22 feet, but produces only a few grains at the bottom of a spongy "cob." In the Southern United States the corn grows to an average height of 15 feet, but the produce is much less than in the Western and Northern States, where the stalk is only from 7 to 10 feet high. Again—following out exactly the same principle—a forester "girdles" a tree, in order to make it bear fruit more luxuriantly. In other words, he cuts out a ring of bark, by which the descending sap, fitted for nourishing the tree, is kept above the "girdle;" the result of which is that the branches above the "girdle" bear flower and fruit abundantly, while the shoots below do not blossom but send out leafy branches. It is for this reason, as any amateur fruit-grower with eyes in his head and the capability of using them knows, that the flowers of most trees and shrubs which, like apples and pears bear large or fleshy fruits, are produced from the side buds resting directly upon the wood of the previous year, in which a quantity of nutritive matter is deposited. So also, a shoot produced from a seed which, if left to itself, would not flower for several years, blossoms the next season when grafted on an older trunk from whose accumulated stock of nourishment it draws, just as a youth if left to work out his own career is often long before he blossoms into prosperity, but if permitted to draw upon the accumulated wisdom and funds of another, speedily attains his commercial majority.

The conclusion we draw from these facts is, that flowering is an exhaustive process, requiring a large amount of nourishment. Yet, if the plant is placed in too rich a soil, it either rots or runs to leaf without bearing flowers. "Annuals"—like mignonette—flower within a few weeks of the seed being placed in the soil; hence they are so soon exhausted in constitution that they die away in a few weeks after blossoming. "Biennials"—like turnips—we have seen, do not flower until they have survived a season, but after they have done so, and exhausted the store of nourishment accumulated in their roots, they die of inanition. But "perennials"—or plants which, like shrubs and trees, last for an indefinite period—do not flower until they are some years old, and thus are better able to bear the strain on their constitution which this reproductive function entails. Even a biennial, no matter how hardy it may be before flowering, will perish at the approach of the succeeding winter, nor can artificial heat preserve it, which shows that it is not the season but the exhaustion of the plant's constitution which kills it. The constitution of plants will, however, change in course of time, and, as is the case of the Indian Cress (*Tropæolum*), a perennial plant of warm climates, may become an annual when introduced into a cooler climate, and there naturalised. Some plants have a predisposition to flower early. For instance, the Bengal Roses (*Rosa semperivens* and *R. Indica*) flower before the seed leaves die away. Feebleness of constitution also assists premature flowering. Hence, plants which have undergone a long sea voyage will often flower immediately after being landed, and then remain blossomless for several seasons following. Taking advantage of this peculiarity, gardeners, by arresting the vigour of a plant, secure flowers at a period when otherwise they would not. If a tree bears abundantly one year, the chances are that the next year's crop of fruit will be deficient. But if the yield is scanty one season, all other things being equal, most likely an excessively abundant supply of fruit will prove that the plant, by accumulating vigour during its long rest, has been enabled to overcome the feebleness which excessive reproduction entailed on it. Annuals, we have seen, are killed by flowering. But the same fatality is exhibited in more gigantic plants than those we usually associate with that name. The well-known bamboo is actually a grass which attains a height of 60 or 70 feet. But after flowering and fruiting it perishes. The sugar-planter is so well aware of this that he cuts his canes before they flower, lest the process should exhaust the juice and therefore rob him of his labour and its profits. Another application of this same principle is the power of the gardener to turn an annual into a biennial or even into a perennial by preventing its flowering. The common mignonette can be thus converted, and cabbage stumps, planted for seed, can, it is said, be made to bear heads the second year by destroying the flower-buds as they arise; and if the process is continued from year to year a plant which is naturally an annual can be converted into a kind of perennial. Again, the common larkspur has given rise to a double-flowered variety which cannot, of course, bear seed, the "double flower" being caused by the reversion of some of the stamens to petals, and has therefore been converted from an annual into a perennial. A more notorious example, showing

the exhaustive nature of flowering, is exhibited by a plant, very familiar, by name at least, to every one—the American aloe (*Agave*), "maguey" or "century plant," which is said to "flower only once in a hundred years." In reality, this, like most popular generalisations, is too arbitrary: it flowers in our conservatories once in a *great* number of years, generally about once in fifty or sixty. In the warm climate of Mexico it produces flowers when five or six years old, but the process is so exhausting that in order to nourish the large mass of flowers the juice—which is drunk when fermented under the forms of "pulque" and "mezcal"—is used up, and the plant perishes after maturing its fruit. Another instance is supplied by the Talipot Palm (*Corypha*), which grows to a great height and produces an abundant crop of nuts. The effort is, however, too much for it, and the tree perishes after the first season.

The production of flowers by a plant differs also from the production of foliage in this respect, that flowering consumes the stored-up products of the plant without giving anything in return. A leaf takes carbonic acid from the air and gives out oxygen under sunlight; a flower, on the contrary, gives back the carbonic acid and water to the air. Fruiting and seeding are also, as we shall see by-and-by, strains on the vegetative life of the plant, but not so great as flowering; and, moreover, the plant in these stages of its existence does not waste what it gets, but stores the nutriment up in the seed for the use of the young plant yet unborn. Another concomitant of flowering is the production of heat over the normal temperature of the plant. In the order of Arads this is particularly noticeable. In the ordinary Cuckoo Plant the temperature is often at this season nine degrees above that of the rest of the plant. In the *Victoria regia*, the great water-lily of South America, it is about six degrees; and in the flowers of a Brazilian plant of the Arad order (*Philodendron*), the temperature has been noticed by Dr. Eugene Warming to rise eighteen and a half degrees while the different organs were developing.

The cause of this increase of temperature is probably due to the fact that at the season of flowering there is absorbed an increased quantity of oxygen, which combining with the carbon consumed as fuel in the plant, produces carbonic acid gas, and evolves an amount of heat duly proportionate to the quantity of carbon consumed, or of carbonic acid gas produced.

When northern trees are transplanted to warmer countries, they often do not flower, owing to their leafing too luxuriantly. It is also noticed that transplanted trees generally flower the first year after their transplantation, though not a second time until after a long interval, because during the first year there has been a check to their growth owing to their transplantation. However, if the tree is not injured or checked in its removal from one soil to another, the contrary fact is true.

It may be put down as a botanical axiom that "a period of rest is required after flowering." In our climate this is afforded by the autumn and winter, when perennial plants form their flower-buds for the ensuing year. In the tropics, where there is often an almost imperceptible difference between summer and winter, the dry season supplies to plants a substitute for our dead season. In the Canary Islands the ground is from April to October baked like a brick, and, with the exception of succulent plants, vegetation almost disappears. This is the plants' season of repose, just as the cold months are in our climate. "The roots and bulbs," writes a well-known botanist, Dr. Asa Gray, to whom we are indebted for these facts, "lie dormant beneath the sun-burnt crust, just as they do in our frozen soil. When the rainy season sets in, and the crust is softened by moisture, they are excited into growth under a diminished temperature, just as with us by heat; and the ready-formed flower-buds are suddenly developed, clothing at once the arid waste with a profusion of blossoms. The vegetation of such regions mainly consists of succulent plants, which are able to live through the drought and exposure; of bulbous plants, which run through their course before the drought becomes severe, then lose their foliage, while the bud remains quiescent, safely protected under ground, until the rainy season returns; and of annuals, which make their whole growth in a few weeks, and ripen their seeds, in which the species securely passes the arid season."

That every plant has its own period for flowering is a fact so familiar to us that we are apt to lose sight of its inexplicable character. Why should the mezereon of our shrubberies flower in February, and the black hellebore in December? Their microscopic structure is identical, and to our eyes there is nothing in their outward appearance or nature which would impose an interval of ten months between their respective periods for producing blossoms. Again, the Primrose expands its flowers in March and April, and the Meadow Saffron in October, yet we are equally unable to

give any other reason for the phenomenon except that "such is the nature of the plant." Inquiring still further into the subject, we see that some flowers, like the Whitlow Grass (*Draba verna*), flower only for a brief period in spring, while the Shepherd's Purse (another member of the same order) and the furze are covered with blossoms from spring to early winter, and even, in the case of the furze, throughout the cold months also. It has been observed that plants which form their flower-buds in the autumn, and wait for the spring sun to expand them, are usually brief-flowered, while those which develop and mature their buds the same season are as a rule covered with blossom for a longer period. Heat seems to have a greater influence over flowering than light, and plants of warm climates if removed to a colder one expand at a later date in the latter than in the former. The Almond, for example, which in Smyrna blossoms in the early part of February, delays doing so in Middle Germany until April, and in Christiania until June. It has also been noticed that if a plant is taken from the northern hemisphere to Australia, it will for the first year flower in winter, the period corresponding to the summer of its native land, but after a time it accommodates itself to the altered state of affairs. Cases have been recorded in which individual plants have flowered year after year before the other individuals of their species, and the gardener, by propagating the plants showing such idiosyncrasies, has been able to obtain certain early, or late, flowering varieties of cultivated trees or shrubs. But, as a rule, plants undisturbed by "civilisation" —in other words, if left to their own devices—have as fixed times—pre-supposing average seasons—for bursting into blossom, as those plants which display the phenomena called "sleep" have of shutting and opening the flowers so developed. It may also be affirmed that every species of plant requires a fixed mean temperature, or a "sum of degrees" of heat for flowering, and that each degree of latitude influences the time of flowering of a particular species a quarter of a day. Moisture also affects flowering in this respect, that wet increases the foliage and thereby acts indirectly in moderating the flower. A tropical forest—florid popular descriptions notwithstanding — is not nearly so luxuriant with flowers as an English meadow—heat and damp, the chief physical agents which act on it, being when in combination more likely to produce superabundance of the "vegetative" rather than of the "reproductive" organs.

Now the facts of which we have supplied but a brief outline have obtained a useful application from the horticulturist, by his varying the conditions under which the plants in the conservatory live, in order to obtain late or early flowers or fruit, as the case may be.

"Forcing," as the writer has pointed out in another place,* is also only an application of these

Fig. 1.—Fertilisation of the Ovule—Anthers discharging their contents on to the Stigma of the Thorn Apple (*Datura*).

principles, and consists in a skilful alternation of the periods of repose by subjecting a plant to heat in a hot-house at one season, and cold in a frigidarium at another. And here I may remark that Arctic plants, unless carefully acclimatised in our gardens, are apt during the first summer they are subjected to the unwonted warmth of the English air, to run luxuriantly to leaf, and die off before they are able to get accustomed during a second season to the southern atmosphere. The cultivator should for the first summer keep them in a cool temperature. He can thus alter the constitution of

* "Manual of Botany" (1874), pp. 294—8.

these hyperboreans, just as he can that of others by giving them an artificial season of rest by the application of cold, and then by the influence of heat, light, and moisture, causing them to grow at a season when they would have been quiescent. Thus, at will, he can retard the periods of flowering and of rest, so as in time to completely invert them.

But flowering—or, in other words, the development of certain organs collectively called the flower, for the corolla and calyx, though most prominent to the eye, are perfectly immaterial to the life of the plant—is only preparatory to another process in vegetable life. This consists in the discharge of the pollen grains (Vol. II., p. 218) out of the anthers,

Fig. 2.—Stigma of the Thorn Apple covered with Pollen Grains. (*Much magnified.*)

to serve a purpose which we shall presently consider. The grains being deposited, by various agencies, on the stigma (Vol. II., p. 219), the ovules after a time become seeds, capable of reproducing the species, and thus carrying on the life of the plant. Numerous curious means are adopted to ensure this end. For instance, the great flowered cactus has about 500 anthers, 24 divisions of the stigma, and 30,000 ovaries, so that in a single flower there must be at least 250,000 pollen grains, an amount far more than is necessary to fertilise the ovules. The wheat plant produces about 50 lbs. weight of pollen to the acre, and in all of the fir and pine family there is also an allowance made for accidents, by the production of more pollen than in ordinary circumstances would be required. When the anthers burst in one of the various ways which we have described, the grains fall on the stigma (Figs. 1, 2) and are then retained either by the natural viscosity of that organ, or by the loose papillæ or hairs which frequently cover it. The grains lie on the surface for a certain time, but they do not burst. They absorb the moisture from the stigma, and this swells and protrudes the inner coat (Vol. II., p. 218) in the form of one or more shut tubes, through the pores or slits in the outer covering (Fig. 3). These tubes, by some sort of

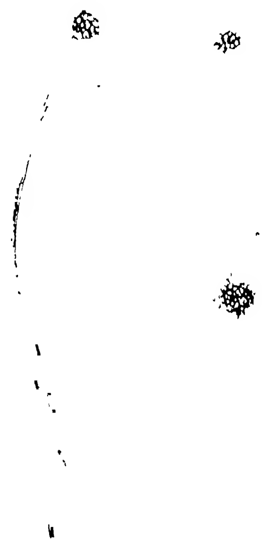


Fig. 3.—Pollen Grains emitting Pollen Tubes. (*Highly magnified.*)

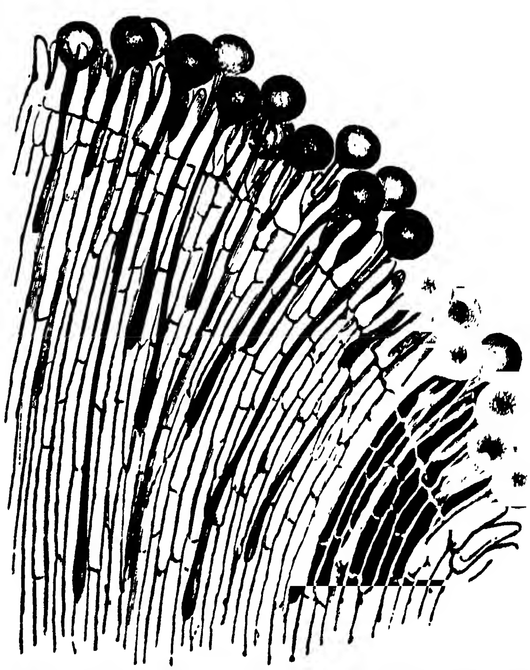


Fig. 4.—Pollen Tubes entering the Conducting Tissue of the Thorn Apple. (*Highly magnified.*)

inanimate instinct, find their way through the loose "conducting" tissue (Vol. II., p. 219) of the style until they reach the ovules, to which they are charged with a mission (Figs. 4, 5). The reader by examining Fig. 6 will see that the ovules are each covered with three coats consolidated below but leaving in the middle of them a minute opening

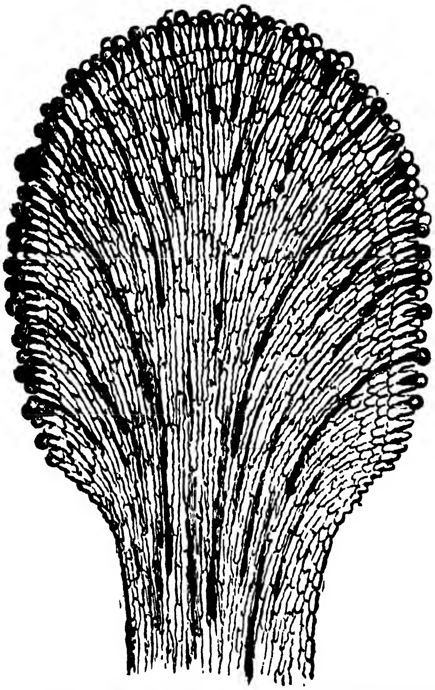


Fig. 5.—Vertical section of the Stigma and Style of the Thorn Apple, showing Pollen Tubes piercing the Conducting Tissue. (*Highly Magnified.*)

(the "microphyle") at the top. Inside these coats is the "embryo sac," a bladder-like organ containing fluid, in which the future plant makes its appearance after the ovule has developed into the seed, and the ovary into the fruit. The pollen tubes grow rapidly, being protruded sometimes immediately after the grains fall on the stigma, but in other cases not until after the lapse of ten or even thirty hours. The tenuity of the tube must be extreme, when—for example—in the great flowered cactus it is 1,150 times longer than the diameter of the pollen grain, and as in other plants the style is several inches long, the pollen tube cannot be less. In the meadow saffron, though the length of the tube is 9,000 times the diameter of the pollen grain, it reaches the ovule in ten or twelve hours.

Now, what happens when this long *cul de sac* of the pollen-grain arrives at the opening in the end of the ovule? It must be remembered that the tube is filled with the fovilla or contents of the pollen grain, which have run into it. As far as can be made out—and there have been endless theories on the subject—the end of the pollen tube enters the ovule, but terminates its travels on the surface of the embryo sac; and by the physical law of "endosmosis" the fovilla passes through the delicate membranes of the tube and the embryo sac into the latter. At all events, after the tube has reached the ovule a change begins in the contents of the embryo sac. Immediately below the place where the end of the pollen tube has fastened itself, a bladder-like cell makes its appearance on the inside of the wall of the embryo sac. Soon, by transverse subdivision and budding of one cell to another this "vesicle" gets elongated until it forms a thread, like a string of beads (Fig. 7). The lowest cell of this cord divides in all directions, until it gradually assumes the form shown in

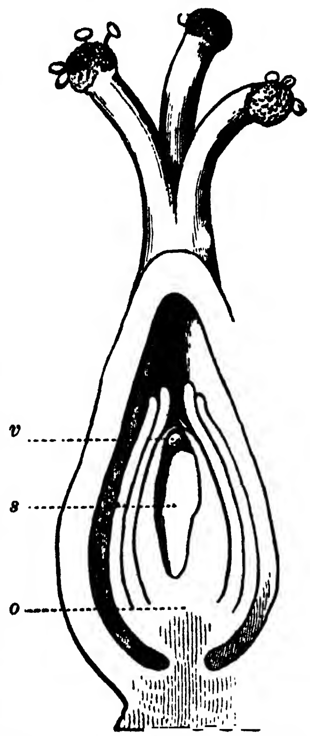


Fig. 6.—Magnified Pistil of Buckwheat.

Ovary and Ovule divided vertically; some Pollen-grains on the Stigmas; one Grain distinctly showing its Tube, which has penetrated the Style, reappeared in the Cavity of the Ovary, entered the Micropyle of the Ovule (*o*), and reached the Embryo-sac (*s*), near the Germinal Vesicle (*v*). (*After Gray.*)

Figs. 8, 9, 10, 11, which are diagrammatic illustrations of a very complicated subject. Thus, we have the "embryo," or young plant, formed, until passing through the stages sketched in Figs. 12, 13, and 14, it assumes the shape shown in Fig. 15, in which we see it with its young leaves already developed, but incapable of deriving nourishment from the earth, into which for some time yet the growing seed will not fall. Hence, around it, or, as happens in some plants—among others beans and peas—in the young cotyledon or seed-leaves, is stored up nourishment for it, until it can draw this from the soil. Meantime a rapid transformation has been going on in the ovule and the surrounding wall of the ovary. The latter, though retaining its fundamental

structure, has altered in many respects, and become the fruit, while the seeds, after fertilisation, have in like manner changed their character somewhat,

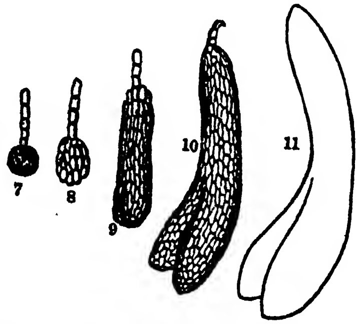
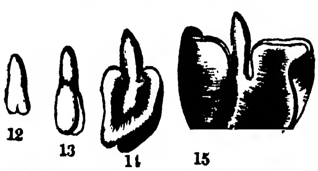


Fig. 7.—Diagram of the thread-like "Suspensor" and Forming Embryo at its extremity; Fig. 8, the same, with the Embryo a little more developed; Fig. 9, the same, more developed still, the Cotyledons faintly indicated at the lower end; Fig. 10, the same, with the Incipient Cotyledons more manifest; Fig. 11, the Embryo nearly completed. (*After Gray.*)

and become the seed. Meantime, the flower has faded. The petals and sepals, if they have not fallen previously, have now either dropped off or withered. The pollen grains, after the pollen tubes have been protruded and sent down through the conducting tissue of the style, have shrivelled up, as have the stigma and style after playing their respective parts in the functions of the plant.



Figs. 12, 13, 14, Forming Embryo from a Half-grown Seed of Buckwheat in three stages; Fig. 15, the same with the Cotyledons fully developed. (*After Gray.*)

In this brief account of a long process we have not taken note of any of the exceptions to the rule, for it is better to fix our attention on the main question, and on the function of the pollen as it is displayed in the great majority of plants. This we have seen to consist in the anthers discharging the pollen grains on to the stigma, in the pollen tube penetrating the style — when it is present—to the ovule, in the discharge, in some unexplained manner, of the fovilla into the embryo sac, and finally in the appearance of the young plant, with the simultaneous absorption of the pollen tube, and the fading away of the parts concerned in its production and functions.

In the heath tribe there is an exception to this rule in so far that the corolla remains behind attached to the fruit; and in the "winter cherry" (*Physalis Alkekengi*—one of the potato order), so familiar an ornament of dinner-tables, the calyx, which is red in colour, survives fecundation, and forms the bladder-shaped covering usually taken for the outside of the fruit, which is, in reality, contained within it. It must also be noted that though in ordinary flowering plants the essentials of the process are the same, it does not invariably happen that the pollen falls out of the anthers on to the stigma of the same plant. In many plants the stamens are on one individual and the pistil on another. Hence the pollen must be conveyed to the latter in some other way than that which for convenience sake we have considered as the normal one. There are, moreover, numerous cases in which, even where the same plant possesses both stamens and pistils, ingenious contrivances can be shown to exist in order to prevent the pollen falling on the stigma within a few lines of it, and to ensure it being carried, by means of insects, birds, the wind, and other agencies, to some other individual of the same species. But these strange and extremely interesting relations of plants to each other and to the animal and even inanimate world, form a subject so wide that it had better be left to another occasion.

WHY THE CLOUDS FLOAT, AND WHAT THE CLOUDS SAY.

By Robert James Mann, M.D., F.R.C.S., F.R.A.S.,

Ex-President of the Meteorological Society.

When water is evaporated into the air under the influence of heat,* the vapour so raised is scattered invisibly amidst the air particles. Both the air particles and the molecules of the water are, however, so minute, and so widely severed in this state, that the vibrations of light pass *almost* as freely and as unimpeded amongst them as they do through empty space. The mixed vapour and air are virtually transparent—that is to say, they allow objects of various kinds to "appear through" or from beyond them in their proper conditions of

* See "Science for All," Vol. II., p. 239.

colour and form, instead of becoming visible themselves. It was essential that this should be the case if the surrounding objects of material Nature were to be freely visible to the eyes of animals living in the midst of circumambient air.*

This absolute invisibility and transparency of aqueous vapour, even under the circumstance of very considerable abundance, is instructively illustrated in the fact that steam is quite imperceptible by the eye so long as it is in its actually vaporous state. If the eye could penetrate into the interior of the boiler of a steam-engine when the part above the water is filled with a pressure of steam almost strong enough to burst asunder the cohesive tenacity of the iron plate, it would be found that such steam was as absolutely invisible as the fine breath of vapour which rises from the earth in

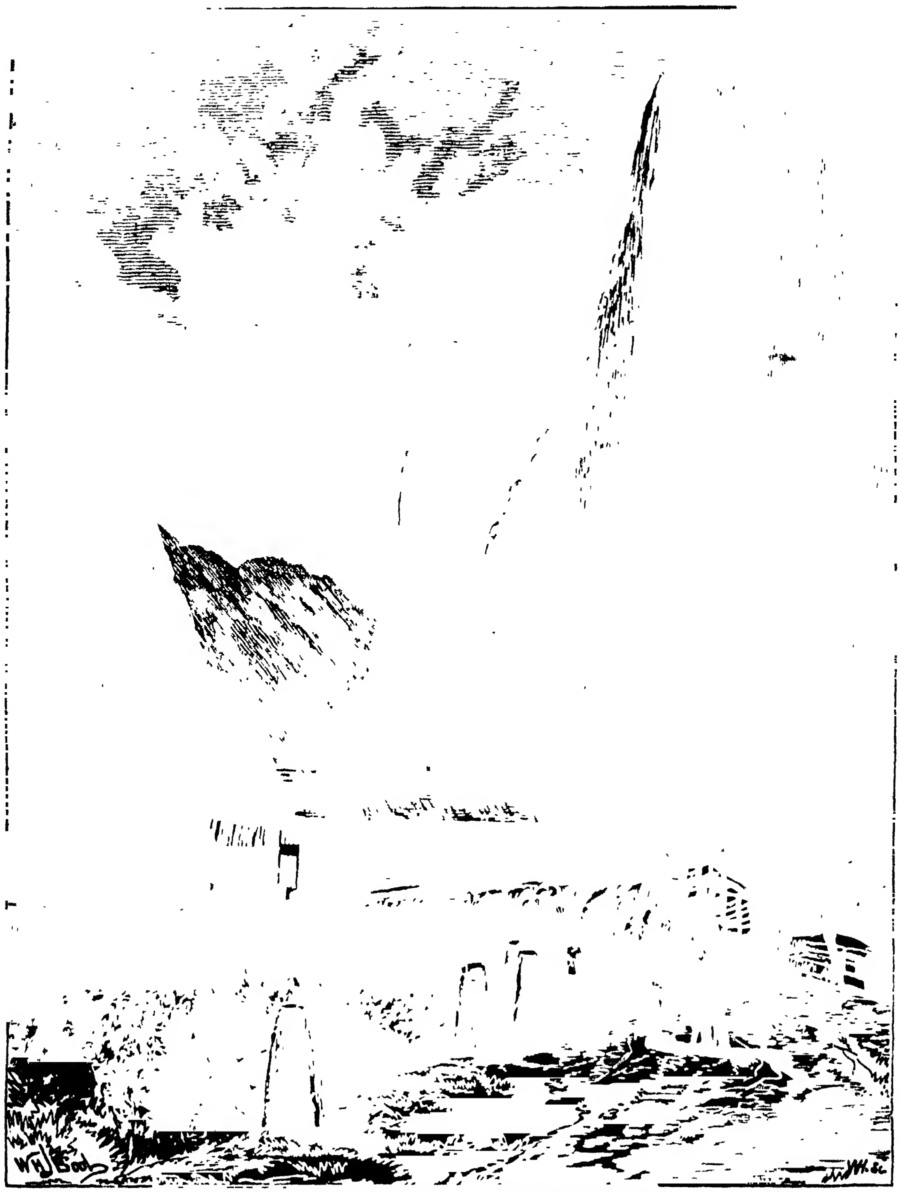


Fig. 1.—The Fall of the Staubbach, in the Swiss Valley of Lauterbrunnen.

* "Science for All," Vol. II., p. 120.

sunshine. The steam which issues from the spout of a kettle of boiling water presents no visible trace to the eye until it has been thrown some distance away into the outer freedom of the air. It only becomes visible as white mist when it has ceased, at that distance, to be actual steam.

The change which takes place when invisible vapour is transformed into visible mist is a very decided one. It is not merely that there is an increase in the quantity of the aqueous particles that are present in the air, for, as a matter of fact, there is a larger abundance of vapour in the clear air of a summer noontide than there is in the thick air of a winter sunset. The change which is brought about is an actual transformation of material state. It is a conversion of air-like vapour into water. The visible particles of mist are clusterings of molecules of water into groups of considerable, and therefore of visible, dimensions. In the white mist the molecules of the water are not evenly and widely scattered. They are so grouped that there are larger spaces between the clustering particles than there were between the molecules of the vapour, and many molecules connected together in those clusterings. It is this gathering together of the molecules in isolated groups, with comparatively blank intervals between, which is comprised in the process familiarly spoken of as "condensation." A similar state is produced to that which is found when liquid water is mechanically broken up into spray. It is then in the condition which has been, not inaptly, spoken of as "water-dust." Thus in the long Fall of the Staubbach,* which plunges headlong from the top of a rocky wall in the Lauterbrunnen Valley in Switzerland (Fig. 1), in a clear leap of nearly one thousand feet, the particles of the water get so severed from each other by the resistance of the air which they have to pass through that before they reach the ground they present themselves only as "water-dust," or drifting mist. Mist is thus a sort of intermediate state lying midway between water and vapour. It appears alike when water is scattered into spray and when vapour is condensing into water.

The clustering of water molecules into granular specks is easily seen in mist by the help of a magnifying-glass. Small opaque bodies, which must contain a very considerable gathering of water molecules in each, are then discerned. These bodies have manifestly a rounded or globular form, such as they would wear if they were minute drops. The Swiss philosopher, De Saussure, who gave considerable attention to their examination, has shown that they are commonly nearly a hundredth part of an inch across, and that occasionally they are very much larger. They are quite twice as large in cold damp days as they are in warm ones. Mr. W. D. Cooley states that he once saw mist globules floating in the air upon Mount Leinster, in Ireland which were half the size of hempseed. The distinguished astronomer, Halley, who was a contemporary of Sir Isaac Newton, first conceived the idea, which has since met with somewhat large acceptance, that these mist specks are of the character of little hollow vesicles, or bladders, in which the outer films only are water, the interior space being filled with air. This conception of Halley was in some measure strengthened by the researches of De Saussure, who ascertained that the visible particles which rise from the surface of warm water during the process of evaporation have quite a different aspect to those which fall from the air during rapid condensation of moisture. He satisfied himself that the rising specks were hollow spheres, or bladders, and that the falling ones were liquid drops. The actual state in which the water particles are arranged in mist is still questioned by competent authorities; but so far as research has yet gone, the notion that mist-specks may be hollow films of water encasing internal nuclei of air seems to possess a fair degree of probability.

The fabrication of visible mist from the condensation of invisible vapour is familiarly illustrated every day in the puffing escape of the waste steam from the funnel of the locomotive as it runs panting along the rail. This white rolling mist which is left in a thick trail behind the funnel of a locomotive engine is, in all essential particulars, cloud. Its close kinship to the heap-cloud which floats above it in the higher region of the air is manifest at a glance. The steam-puff is miniature cloud wreath artificially formed. It is visible to the eye on account of its coarse-grained texture. It is not freely permeable to light, because the clustering spherules, or vesicles, arrest the luminous vibrations which fall upon them, and send these back to the eye, and because these light-reflecting spherules are distributed in a deep bed, in which the more remote individuals present themselves through the clear spaces that lie between the nearer ones. The cloud is white or grey, accordingly as its spherules reflect, or absorb and hold, more or less of the incident light. It is dark when it holds back the chief part of the luminous vibrations which fall upon it, and

* From Staub, dust; and Bach, a brook or rivulet.

it is white, like snow, when it freely reflects the whole.

The fundamental and primary form in which natural cloud appears is the very beautiful and distinct one which is seen on most ordinarily fine days sailing grandly across the blue sky, and which is designated the *Heap-cloud*, *Mount-cloud*, or *Cumulus*,* because it assumes the aspect and shape of rounded masses piled up in heaps (Fig. 2).

Luke Howard, the meteorologist who first attempted a scientific classification of the clouds, and who printed an admirable treatise on the subject in 1803,† tersely and accurately defined this primary form as "Nubes cumulata, densa sursum crescens"—a dense, heaped-up cloud, increasing above. The rolled heap-cloud, indeed, may not inappropriately be regarded as Nature's steam wreath, formed when warm vapour-laden air is puffed up into the colder and rarer regions of the atmosphere that lie a few hundred feet above the earth. In the case of the cloud the warm moisture-laden air is not shot out from the inside of a furnace-heated boiler, but it is shot up from the surface of the sunshine-heated ground. When the sunshine falls upon the heat-absorbing soil, the air which rests in immediate contact with it gets warmed by the touch, and expands as it is warmed, drinking up at the same time whatever moisture is rising up into it from the earth in the condition of vapour. The expanded air is then driven directly up from the ground by the pressure of the inflowing, heavier, and colder atmosphere from around and above, and as it rises, balloon-like, under the influence of this pressure, it carries with it the aqueous load which is entangled amidst its particles. As it mounts up, however, in the atmosphere, it is first expanded still more on account of the diminishing air weight above, as it escapes gradually from the superincumbent load, and is immediately after chilled, in part as a consequence of its own expansion, and in part because of the lower temperature of the high region which it has reached. Under this double influence, the air expansion and the chill, the invisible vapour gathers itself into mist spherules, and appears as visible cloud. Professor Tyndall happily speaks of the rolling masses of the heap-cloud as being the "capitals" of underlying columns of warm air. Wherever the air is heated by resting upon the warm ground it is forthwith fashioned into an ascending, although unseen, air-column, which crowns itself with a capital of wreathing cloud as soon as it has got high enough to chill the entangled water molecules into clustering spherules of condensing liquid.

Fig. 2.—The Heap-cloud, or *Cumulus*.

But in order to accomplish a complete comprehension of this process of cloud manufacture it must be understood that these mist capitals of the warm air-columns are cut off from the pillars, and wafted away as soon as they have been formed. The heap-clouds invariably are seen *to drift along in the sky*. The fact simply is that as soon as the ascending columns of warm air reach the cool upper regions, where transverse currents, instead of ascending ones, prevail, the rolling mist wreaths which are precipitated from the air are carried away by the wind. The so-called *floating* of the clouds is simply a matter of *drift*. Water is 815 times as heavy again as air, consequently it must fall when deposited in air, as, indeed, it is actually seen to do in the case of rain-drops. If clouds, therefore, are composed of liquid water gathered out of the vapour, they should fall and not float. Some ingenuity has been expended by scientific men in the attempt to account for this apparent anomaly. No large effort of intelligence, however,

* From *Cumulus*, a heap.

† "An Essay on the Modification of Clouds," by Luke Howard, F.R.S. (1803).

is really required to enable this to be done satisfactorily. A glance of the eye on the white mist heaps in the sky is enough to furnish the full solution of the mystery. Clouds never rest still in air; they are at all times *in motion;* they are always in the act of being blown along by the wind. When rain-drops fall at the time that a strong wind is blowing, even they are observed to be carried a considerable distance along; and if the rain-drops were lighter than they are they would be carried still farther by the wind before they finally reached the ground. If, for instance, they were hollow, air-filled balls, like balloons, instead of being compact drops of liquid, they would assuredly drift upon the wind long distances, and this, it will be remembered, is precisely what cloud spherules are. They are hollow balls, constituted of the lightest and thinnest conceivable films, and therefore possessing very large surfaces in proportion to their weight. They are just in the condition which fits them to be seized and hurried along by the drifting air currents. When clouds exist in really still air, their spherules do fall. It has been ascertained that aqueous mist, by falling through some three thousand feet of air, can acquire a downward velocity of something like fifty inches per second. It would indeed fall with the headlong impetuosity of a leaden bullet or a stone, but for the resistance which it encounters in making its way down amongst the air particles. When, therefore, the air is itself moving, instead of being at rest, this resistance to its descent becomes an actual carrying power. In all probability, electrical force at times has something to do with the suspension of cloud. But there can be no doubt that, in the main, the result is merely the effect of a mechanical influence—that it is a case of drift rather than of buoyancy. The notable instances in which clouds appear to be still are all simply illusions. In such cases the cloud is in the process of being dissolved away at one edge as fast as it is deposited at the opposite one, and so it is the visible form only, and not the substance, which is still. The table-cloth which frequently covers the top of Table Mountain, at the Cape of Good Hope, is a cloud of this character. The moist air from the south-east is blown from the warm sea up the slopes of the mountain, until it is high enough to deposit its vapour as white mist, and it then passes over the flat summit of the mountain, and falls on the opposite side, until it gets back into the lower and warmer region, where the white mist is again dissolved into transparent vapour. In mountainous countries it often happens that all the summits of the lofty mountains are cloud-capped, whilst the intervening spaces of the atmosphere are clear. The same explanation applies to this. The cloud is deposited where the air is chilled by the close neighbourhood of the snow-covered summits, but is dissolved as soon as it is drifted away clear of the mountain into the warmer stretches of air. The white cloud-caps are thus not stationary clouds but fresh clouds continually formed, and as continually dissipated as they move from the place where each white cap is seen.

The heap-cloud, or cumulus, is properly a day cloud. It begins to appear in the early morning, as the ground gets warmed enough by the sunshine to establish ascending currents of air. It rises into higher regions of the atmosphere and assumes its largest dimensions soon after noon, and it then sinks and dwindles away towards evening. It belongs also properly to the mid-region of the air, ascending to a somewhat higher elevation at mid-day, and sinking to a lower one in the evening. It is also a cloud of land districts rather than of the sea, as heated ground is required to establish the upcast of the air currents. But when it has once been formed over the land it is capable of being drifted away long distances over the sea, as it invariably is in the great currents of the trade winds which prevail in the intertropical regions of the ocean. When these cumulus clouds observe their normal rule of growing in size and rising in height at midday, and of diminishing in size and sinking in the evening, they are invariably indications of settled weather; but when, on the other hand, they grow in size and in density as they subside in the evening, they indicate increasing moisture and greater chill in the lower regions of the atmosphere, and may be regarded as certain harbingers of approaching rain.

In settled fine weather, when there is not moisture enough in the ascending currents of the air to form heap-clouds in the mid-region of the atmosphere, faint streaks of white cloud appear flecking the blue sky-canopy, far above the region where the heap-clouds should sail. A few delicate threads are first pencilled out on the azure background, and these then grow by the addition to them and interlacing with them of new strands. The streaks sometimes assume the form of feathers, or of tufts like flowing horse-tails; sometimes they are parallel to each other, and sometimes they cross and interlace like the meshes of a net; sometimes they diverge like the fingers of a hand, and very

frequently they are curled up like locks of hair. In all these diversities of form, however, they are of a thin filmy nature, and in all they present themselves only at very high elevations, being commonly as much as five or six miles above the ground.

Fig. 3.—Primitive Forms of Curl-cloud, or Cirrus, constituted in the higher regions of the Atmosphere.

These filmy cloud streaks of very elevated regions are all classed as the *Curl-cloud*, or *Cirrus* * (Fig. 3).

The white streaks in these clouds seem to be formed by particles of snow or ice rather than by vesicles of water. On account of the dryness of the air, no deposit of visible mist occurs excepting at an elevation in the atmosphere that is cold enough to deposit ice instead of water, which then arranges itself in the state of spicules, or needles, of the most exquisite delicacy and fineness. This cloud is thus *ice-dust* rather than water-dust. During steady high winds the cirrus streaks not uncommonly run quite across the sky, arranging themselves as they do so in the direction of the wind. Very often they are bent up at the end which is forward in the drift, as if they were there lifted into bellying sails to catch the wind. This delicate or frost-cloud, is formed far above the summits of the highest mountains. The well-known German meteorologist, Kœmitz, states that during a residence of eleven weeks near the Finsteraarhorn, the highest mountain of the Bernese Oberland, he never once saw the cirrus-cloud as low as the summit of the mountain, which is 14,026 feet above the level of the sea. The travellers who climb such mountains, on the other hand, see the heap-clouds floating in the valleys far beneath their feet, and it is a not uncommon event for such travellers to have the cumulus-clouds below them in the morning, above them one or two hours after noon, and around them in the intermediate hours which lie between the early afternoon and evening.

When, in consequence of a sudden increase of moisture from the drifting in of a vapour-laden wind, the streaks of the curl-cloud in the upper region of the air become more abundant, they at length get woven out into a continuous stratum, or bed, and at the same time settle down to a lower level on account of their augmented density. The cloud, however, then receives a new name amongst meteorologists. It is termed the *Thread-cloud*, or *Cirro-stratus* (Fig. 4). It is properly the streak-cloud, or Cirrus, passing into the state of *Sheet-cloud*, or *Stratus*.† The streaks are woven out into a thin layer or misty web, which is thinned gradually away towards the edges all round, and therefore assumes the appearance of a long, narrow band with pointed extremities when seen in profile, low down towards the horizon.

It is from this peculiarity that it has received the familiar designation of thread-cloud. In its completed form it is a cloud of considerable lateral extent and of small perpendicular depth; the fibres and streaks of the cirrus, in its fabrication, settle down into a horizontal position, approach each other, and finally interweave, or fuse themselves

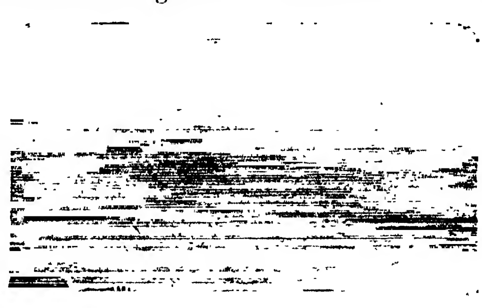


Fig. 4.—Bands of Cirro-stratus, or Thread-cloud, passing into the state of Stratified Beds.

* From *Cirrus*, a curl.

† From *Stratus*, strewed, or scattered, as it were, into a bed.

into a continuous layer. The streaks not uncommonly assume the grained appearance of polished wood. The beds are almost always thick in the middle and thinned out towards the edges. In the distance the pointed cloud-masses occasionally look like shoals of fish. The mackerel-back sky is also caused by a variety of this kind of cloud. The cirro-stratus, when abundantly developed and persistently maintained, almost certainly indicates the approach of wind and rain.

In all probability the cirro-stratus cloud still retains in some degree its frozen condition. It still has the sharp lines appropriate to the ice-dust of which it is composed.

But the ice is gradually approximating to the state of water with the thickening and descent of the cloud. When this gets low enough the frozen spicules are quite melted into water, and the stratification of the cloud is then broken up into separate mottlings, scattered like flocks of carded wool upon the sky. This is the form which is distinguished as the *Curdled-cloud*, or *Cirro-cumulus* (Fig. 5).

It is the sheet-cloud, or cirro-stratus, in the process of being re-modelled into miniature cumuli, and is regarded as a kind of intermingling of cirrus and cumulus, as its compound technical name indicates. The cirro-cumulus was well described by Luke Howard as consisting of "small, dense, roundish cloud-masses, grouped like a flock of sheep." It is the cloud of the mottled sky which occurs so frequently in summer, and which is also occasionally seen in the intervals between showers in winter time. It is constantly formed from the subsidence of cirro-stratus into the lower and warmer regions of the air, and when this is the process of its formation the flocculi of the cloud are slowly and gradually dissolved away. It not uncommonly appears at the same time with the cirro-stratus, and alternates with it, the one or the other form predominating accordingly as there is increasing deposit or loosening and dissolving away of the cloud-mass. As a general rule, the true curdled-cloud indicates increasing warmth, diminishing moisture, and a tendency towards fine weather.

Fig. 6.—Cumulo-stratus Cloud.

Fig. 5.—Curdled-cloud, or *Cirro-cumulus*, formed by the dissolving away of Stratified Cloud-beds into separate Flocks.

The streak-cloud, however, is not the only cloud which is prone to gather into continuous masses. The heap-cloud, in very moist states of the atmosphere, does the same thing; but the accumulation is then deep as well as broad. The cloud-mass is piled up higher and higher, and the rolling heaps are connected together by horizontal beds. The cloud is then looked upon as being a combination of the heap-cloud with the streak-cloud, and is on that account technically distinguished as *cumulo-stratus* (Fig. 6).

The rolled form of the cumulus can generally be traced for a long time in the thickening and growing mass. In the first instance it towers up in projecting summits above the stratified base, but subsequently the rolled protuberances overflow at the sides, and hang down from the flat bed, until at last the whole sky gets to be filled with one dense and undistinguishable mass. But when this dense mass floats away towards the distant horizon it is

finally seen there as a flat drift overlapped by rolling summits which at times very closely simulate the aspect of snow mountains.

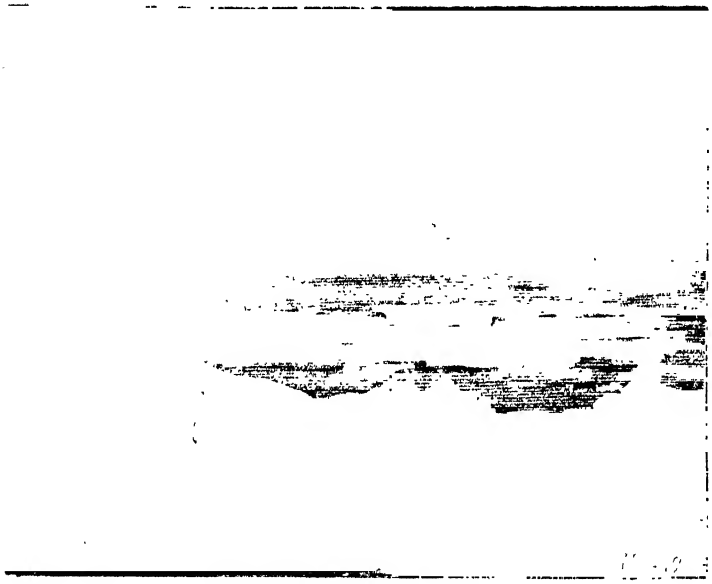


Fig 7.—*The Nimbus*, or Rain-cloud.

The immediate tendency and the final destiny of the cumulo-stratus cloud is obvious at a glance. It is the parent of *The Nimbus*,* or *Rain-cloud* (Fig. 7), which was also classed by Luke Howard as *cumulo-cirro-stratus*, because it was regarded by him as a confused intermingling of heap-cloud, streak-cloud, and sheet-cloud—a congeries of clouds pouring forth rain.

In the formation of the rain-cloud the lower clouds spread out in all directions until they unite into one uniform and compact homogeneous mass, from which the gathering rain-drops fall. The distinctive characteristic of the rain-cloud is the thick, impenetrable confusion of its homogeneous mass, and the streaky, undefined shading away of its outer edges.

In his original sketch of the classification of clouds, Luke Howard recognised three primary forms, and considered that all other kinds were secondary productions compounded from these. The types which he adopted as the primary ones were the streak-cloud, the heap-cloud, and the sheet-cloud (cirrus, cumulus, and stratus). The streak-clouds he held to be the clouds of the higher regions of the atmosphere; the heap-clouds those of the mid-regions; and the sheet-cloud, in his acceptation, was the creeping mist which rests upon the water or upon the ground, and which is now more accurately distinguished as *Ground Fog* (Fig. 8).

The stratus was, with him, the cloud of the night, as contrasted with the cloud of the day. He described it as appearing about sunset, often continuing through the night, and as vanishing with the return of the sun, and either evaporating and disappearing upon the breeze, or ascending into the higher region to feed the heap-cloud. Howard, nevertheless, although he mainly restricted the term stratus to what is now distinguished as fog, recognised some similar constituent as being present in the compound clouds at all elevations.

There is one hitherto unnamed, yet remarkably distinct and interesting form of cloud which has been brought to the notice of meteorologists by Mr. Clement Ley.† It is a very high cloud, rarely appearing so near to the ground as 14,000 feet,

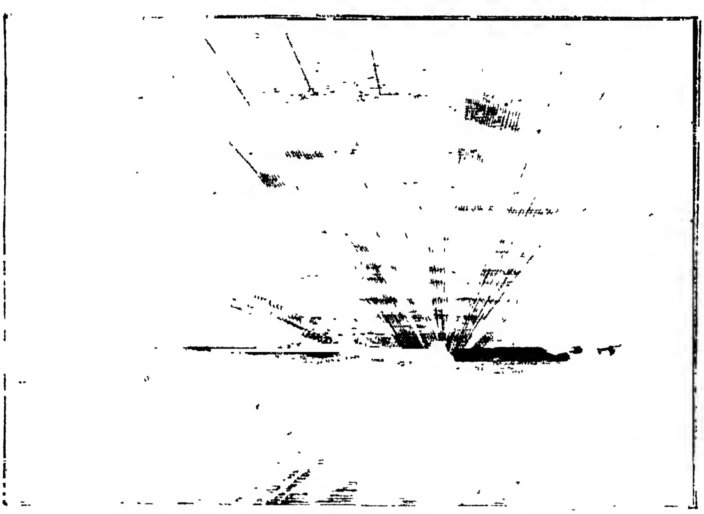


Fig. 8.—Ground Fog, the Stratus-cloud of Luke Howard.

* From *Nimbus*, a dark rain-cloud.

† See "Modern Meteorology," a series of lectures ... under the auspices of the Meteorological Society (1879).

and is essentially a continuous layer of sheet-cloud, with numerous turret-like protuberances rising up out of the horizontal bed (Fig. 9).

This cloud is of an exceedingly beautiful form, and is not unfrequently mistaken for a modification of cirro-cumulus. It has, however, nothing of cirrus about it, and should rather be classed with cumulo-stratus, to which it is more naturally allied. It is most generally seen during the prevalence of very hot weather, and is essentially connected with great electrical disturbance in the higher regions of the atmosphere. It is the constant precursor and herald of violent thunderstorms.

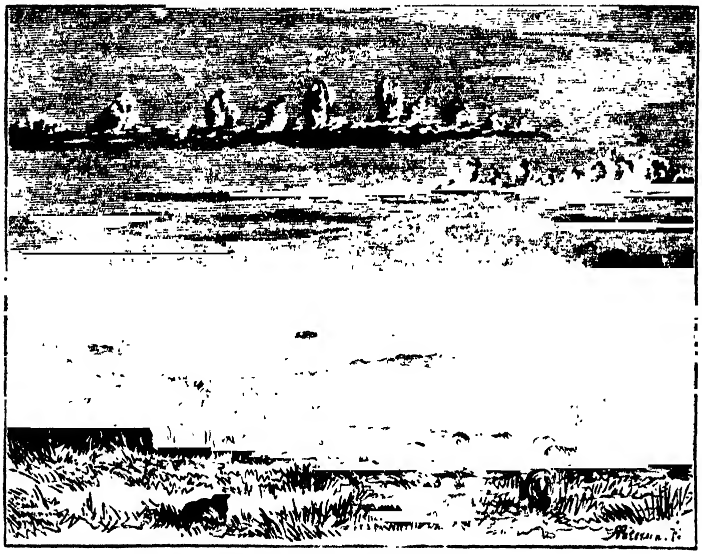


Fig. 9.—The Cumulo-stratus Cloud of Mr. Clement Ley.

A somewhat practical modification of the now classical cloud system of Luke Howard has been suggested by Professor Poey, of Havanna, in Cuba. He proposes that the great sheet-cloud of mid-region, formed by the agglomeration in itself of cirrus, cumulus, and stratus, should be called the *Pallium*,* or *cloud-cloak*. In its most complete form this pallium-cloud spreads as a grey or ash-coloured veil over the whole face of the heavens, with rain precipitating from it for hours at a time. But there are two quite distinct states in which it presents itself. The first of these, which is the proper representative of the cirro-stratus, and which is constructed out of the cirrus and stratus in the higher region, Professor Poey terms the *Pallio-cirrus*, or *sheet-cloud*. In the second variety the cloak is formed below instead of above, and is constituted by the densely-gathering vapours in that lower region of the air. This properly is the rain-cloud, or nimbus, of Luke Howard's system. But Professor Poey designates it the *Pallio-cumulus*. He considers that the high pallio-cirrus is a frost-cloud, and the low pallio-cumulus a water-cloud. But the two constantly co-exist as separate beds, and then have an interval of clear air resting between. The upper pallio-cirrus is first formed on the approach of rain, and is of longer continuance. When fine weather passes into wet, the upper sky-mantle first collects and settles down, and then the lower mist-mantle begins to appear. As fine weather returns, the lower mantle first thins away and breaks up, and the higher pallio-cirrus is then seen through the chinks, floating as an unbroken stratum above. Professor Poey also recognises another form of cloud which was not distinguished by Luke Howard, although it is well marked and of constant occurrence. It is what he terms the *Fracto*†-*cumulus*, or *wind-cloud*. It is really, however, only the disintegrated and torn fragments of the denser clouds drifting away upon the wind when the pallio-cumulus is broken up. It is at once distinguished from the heap-cloud by its torn and tattered look. It is shreds rather than heaps of cloud, hurried along out of the dissolving wreck by the wind. Professor Poey's cloud system thus consists of—(1) the high snow and ice-clouds; (2) the low vesicular, or water-clouds; (3) the cloud-mantle, which is fed both by the high ice-clouds and by the low water-clouds; and (4) the wind-clouds, torn out of the dissolving cloud-mantle.

It thus appears, upon a general review and summary of these recognised modifications of clouds, that—

The cirrus is the cloud-streak, formed in the highest regions of the air by the chill touch of frost.

The cirro-stratus is the cloud-web, woven when these frost-streaks are multiplied as they descend into regions of more copious moisture.

The cirro-cumulus is the frost-cloud, stippled and rounded away when the ice-dust is melted into vesicular vapour.

* From *Pallium*, a cloak.

† From *Fractus*, broken—fragmentary or wind-broken cloud.

The cumulus is rolling wreaths of vesicular vapour thrown down out of ascending upcasts of warm, moist air, when these reach the influences of combined rarefaction and chill.

The pallio-cirrus is the high ice-cloud, thickened into a broad mantle by increasing moisture.

The pallio-cumulus and cumulo-stratus are the low rain-clouds, overflowing with precipitating moisture and dripping with showers.

The fracto-cumuli are the wind-torn fragments of disintegrating rain-cloud.

When the rain-cloud has become overcharged with its condensing vapours, the aqueous vesicles of the gathering mist first grow large and heavy, and then several of them coalesce and form a liquid drop, which, when it has reached the size of about one-eightieth part of an inch in diameter, begins forthwith to descend through the air by the mere influence of its weight. If this rain-drop starts from a comparatively high, and therefore chill, region of the atmosphere, it grows in size as it reaches the warmer and yet moister regions below, by condensing more moisture upon itself, until it has attained considerable dimensions. Rain-drops a quarter of an inch in diameter have been seen. A rain-drop of this size may acquire a velocity of thirty-four feet per second in falling, but not more, because the resistance of the air prevents increase of speed beyond that amount. A rain-drop the twenty-fifth part of an inch in diameter cannot acquire a greater velocity in falling than thirteen feet in the second; and a drop the seventy-fifth part of an inch in diameter cannot acquire a speed of more than eight feet per second. A water-drop the thousandth part of an inch in diameter would have two inches per second for its greatest velocity. When, however, a rain-drop passes through a stretch of comparatively dry air below, it evaporates and diminishes in size, instead of increasing, as it descends. As a matter of fact, it not unfrequently happens that actually falling rain does not reach the earth, but is entirely dissolved and again taken up by the air before it gets there. Indeed, it is no uncommon thing to see rain-clouds in flat countries, in the spring, pouring out their grey bands of rain near the horizon, with a ragged fringe of attenuated ends hanging down from them below towards the ground, but not reaching it.

HAIRS AND SCALES.

By John H. Martin,

Author of "Manual of Microscopical Mounting."

PHYSIOLOGICALLY speaking, hairs are but scales rendered longer, by the necessity of the animal requiring them—from the hide of the rhinoceros to the filmy scale of the herring, from the mane of the lion to the silky hair of the Cashmere goat. Nature fulfils her purpose—hairs, horns, hoofs, nails, and scales, are composed of *nearly* the same chemical substance, though in regard to their structural character they vary much.

Hairs are developed from the interior of follicles (glands) which are contained in the skin of nearly all the Mammalia. Hairs when secreted from these glands consist of modified epidermic structure —that is, partaking of the same tissues as the skin itself. The meaning is more thoroughly explained in Fig. 1.

The skin of animals is composed of three principal parts. The outer, which is cellular in structure, is called the "cuticle;" the next, which is of fibrous tissue, the "true skin." Under these structures, which compose the skin-proper, is a third,—the sub-cutaneous (under the skin) tissue.

The outer layer of the skin, which is entirely cellular, is comparatively of little value, being constantly renewed from the "true skin."

Hairs, it has been noted, consist of the same structure as the skin—being merely elongations of it. Between the cuticle and the "true skin" is a layer of cells containing pigment, and called the "rete mucosum." From these cells the colour of the skin is derived, and they also give the coloration to the hair.

Having thus briefly mentioned the structure of the skin, we follow up our subject with the examination of human hair. On pulling a single hair from the beard or scalp, a bulb-like appearance is evident at its point of growth (Fig. 1). This hair consists of three parts—that is, the shaft, the root, and the bulb, which last part rests within, and

derives its nourishment from, the hair follicle. The diagram (Fig. 1) gives the due explanation of these structures.

The rete mucosum just mentioned is extremely interesting, composed as it is of a pigment structure covering the true skin and separating it from the cuticle. In many animals these pigment cells alter their forms and position according to given circumstances of light and heat (Fig. 2); instance the changing of colour in foxes, various reptiles, &c.* But this structure can be best treated in regard to its giving colour to the hair.

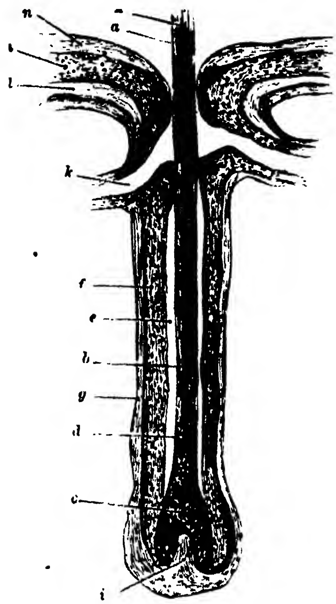


Fig. 1.—Human Hair and Follicle.

(A) Shaft of Hair; (a) Cortex; (b) Root; (c) Bulb; (d) Cuticle of the Hair; (e) Inner Sheath of the Root; (f) Outer Sheath; (g) Membrane of the Hair Follicle; (i) Papilla; (k) the Ducts of the Sebaceous Glands; (l) Cutis of the Orifice of the Hair Follicle; (m) the Rete Mucosum; (n) Cutaneous Epidermis.

A hair when pulled from the card should be soaked in turpentine for a few inutes, after which it should be mounted in Canada Balsam in the usual manner. When thus prepared, and then observed under the quarter-inch power of a microscope, two distinct parts are immediately noticed. First, we see an inner and darker part springing from lower part of the bulb, and passing upds through the root to the extremity of the t (Fig. 1); this part is called the medulla. ndly, the exterior part surrounding the "medulla" or "marrow," is composed of cells more or less elongated: these are called the cortex (Latin for the outer part).

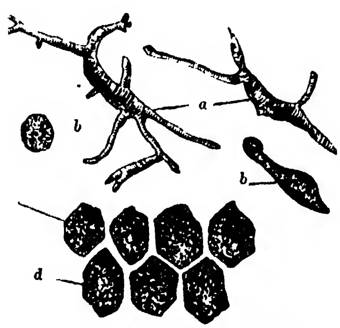


Fig. 2.—Cells of the Rete Mucosum. (After Carpenter.)

igment Cells from Skin of Tadpole; (b) the ie in process of formation; (c) Cells from a of Negro; (d) a Pigment Granule.

* "Science for All," Vol. I., pp. 251-8.

Although the cells of the medulla appear dark from a casual observation, it will be found on further examination that this is caused by their containing air. To prove this, take two hairs; cut about half an inch from the centre of each, and roughly mount one of them in turpentine, the other in water. If this is quickly done the air in both cases will be seen escaping from the ends of the hairs, thus proving its presence. When I say mount quickly, I mean simply place the hair between the clean glass (three inches by one inch) slide, and the piece of thin glass, used by microscopists; cover with a small india-rubber elastic band to keep all in

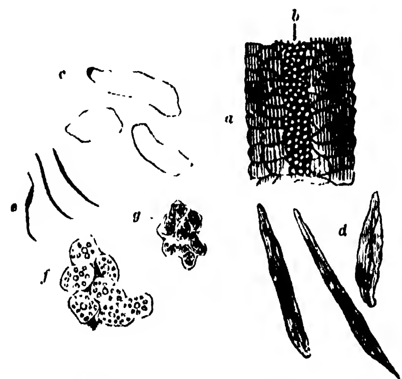


Fig 3.- Microscopic Structures of Human Hair.

(a) Human Hair, sho...g Epidermic Scales in position, and also Cortical portion of the Hairs; (b) Cells of the Medulla; (c) the Epidermic Scales more Magnified; (d) Cortical Scales Magnified; (e) Pigment Cells of the Cortex; (f) Fatty Cells from the Medulla; (g) Pigment Cells from the Medulla.

place; then allow the turpentine or water to flow in by its capillary action (p. 63). By following these directions the hair can be quickly observed.

If the piece of hair that has been saturated with water be dried, it will again become dark in the centre, and the air may afterwards be dispelled by the same method.

It is thus proved that the medulla of the hair does not contain the cells which give colour to the hair, though no doubt it adds to its richness of tint (Fig. 3).

If the medulla had been composed of pigment cells their presence would have been proved by the use of the turpentine and water, the action of these liquids being as follows:—Turpentine would have caused the pigment cells to become more transparent, but their real colour would have remained nearly unaltered; the action of the water would have been still less noticeable, as the colour would have remained unaltered.

The outer or cortical part gives the hair its colour, as well as its elasticity and firmness. The coloration, or pigment granules, are derived from the pigment granular cells of the rete mucosum of the skin during the growth of the hair. These granules of pigment are very minute in size and round in form, and, as they exist in the healthy hair, are grouped in lines between the elongated and flexible cells of the cortex. The pigment granules can be separated from the cells of the cortex by the action of a solution of caustic soda, or potash, (Fig. 3, e). Towards the bulb of the hair the cells of the cortex are much less elongated.

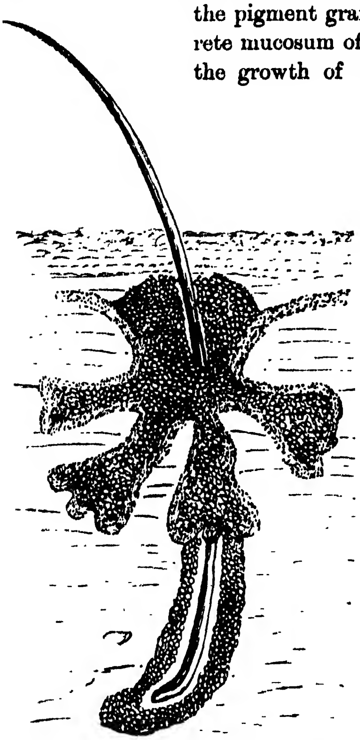


Fig. 4.—Sebaceous and Hair Follicles.

Both the shaft and root of the hair are covered with thin, flat, "imbricated," or overlapping, scales, which adhere very closely, so much so that when the hair is in a perfectly healthy and mature state, it is difficult to see them, even under a high power of the microscope, but in the hair of an infant, and that of an adult during certain diseases, they are more apparent.

The hair of the lower animals differs but little in general structure from that of man, the chief difference being, that beneath the stouter and darker hair there is a shorter and finer downy or woolly hair; the medullary cells also vary much in regard to their size and position in the root and in the root and shaft.

The hair follicles are generally imbedded in the cutis, though in the case of long hairs they are often seated as deep as the subcutaneous tissue. The complexion, to a certain extent, rules the colour

Fig. 5.—Fibre of Wool, showing Scales.

of the hair; for instance, in the fair Saxon and in the dark negro. Light, heat, climate, food, &c., have possibly had more to do with the colour of the hair than anything else, the pigment cells of the rete mucosum being, no doubt, greatly acted upon by the increased secretion of the sebaceous follicles, arising from the heat of the climate. Cells from the rete mucosum often show a "molecular movement" of the pigment granules after the skin is taken from the body. There is therefore but little doubt that intense light acting upon this remarkable tissue causes the pigment cells to

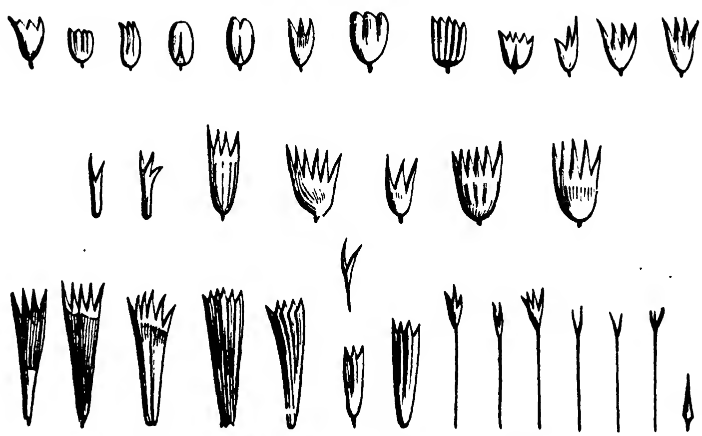


Fig. 6.—Different Forms of Scales of Butterflies.

increase and aggregate according to the amount of light absorbed, until these aggregations cause the skin to assume various shades, varying from white to brown and black. In connection with this subject I may state in passing that analyses of

these pigment cells have proved over fifty per cent. of pure carbon to be present. In the case of the frog and other reptiles, the pigment cells are not always round. Occasionally they occur as star-shaped cells (Fig. 2). The skin of the common frog is one of the best examples, as it changes its colour something like the chameleon—according to the state of the light, heat, and pressure of the atmosphere.

In diseases of the skin, the blood rushes with greater force to the surface; in this case, therefore, the "true skin" is greatly stimulated; thus, the cuticle and also the epidermic, or epithelial scales, are constantly in the process of renewal. Thus it would be better to strengthen these tissues by using a pure animal oil, which would add strength to the hair as well as to the skin, being readily secreted by the sebaceous follicles, and gradually conducted by them to the hair follicles into which they flow (Fig. 4).

It is evident, therefore, that if the hair is weakened in colour or otherwise, the only remedy that can be applied is to strengthen the skin, either internally by giving strength to the individual, or, as before mentioned, by the moderate use of pure animal oil.

If the sebaceous follicles are diseased, the only apparent remedy would be a long course of perspiration-causing medicines, together with proper tonics.

To the student a never-ending variety of structure is present, both in regard to the internal and external tissues. Whilst human hair is smooth, the hairs of many animals are rough, hence their use in the economy of nature; the hair (wool) of the sheep and goat family supply millions with warm clothing. The structure necessarily required for felting is contained in the hairs of but few animals apart from those just mentioned.

The appearance and use of wool are well known, but its value as a felting hair is as much due to its curling manner of growth as to its imbricative surface. The felting principle will be easily understood by referring to Fig. 5. All felting hairs have the outer part of the cortical structure much looser; this of necessity causes the surface to be of a more imbricative nature. The hair of the monkey order is nearly the same as in man; the air cells of the medulla are, however, much larger. The bat tribe have beautiful hair, well fitted for felting purposes if they existed in sufficient numbers to allow of its being utilised.

But it is in the hair of animals of the order of ruminants that the felting principle is chiefly found. This order, containing as it does the

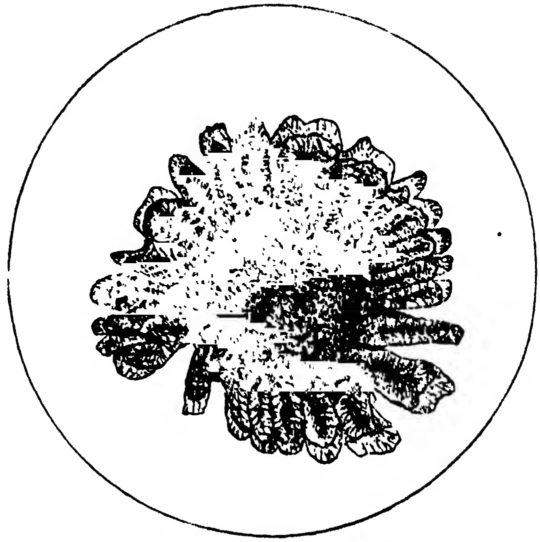


Fig. 7.—Ganoid Scale—Sturgeon.

numerous varieties of sheep and goats, may be said to supply at least four-fifths of our material for felting purposes; and with due selection, it is highly probable that new varieties will be bred of much higher quality than those at present in

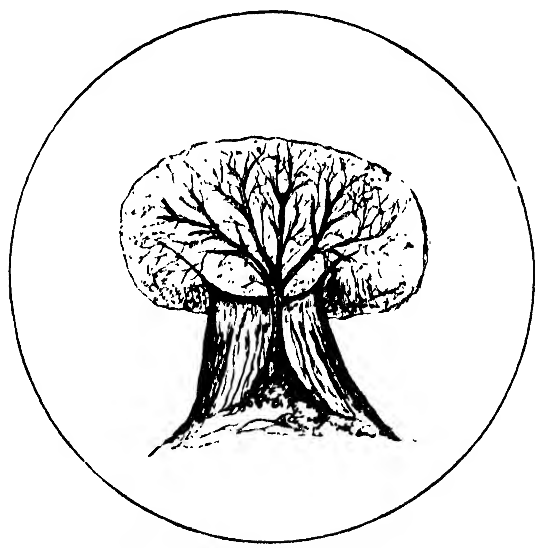


Fig. 8.—Placoid Scale—White Shark.

use. To scientific observers the numberless forms of the minute hairs and scales of insect life are full of interest, and though from a practical and commercial point of view they are of course valueless,

their beauty of form and colour may be said to be marvellous (Fig. 6).

A few years ago the scales of fishes were thought to have the same epidermic structure as the hairs, nails, &c., of the higher animals, but it is now proved that these structures are different, more so perhaps in their chemical composition than in their form. Fishes, in regard to their scales, have been conveniently classed under four orders.

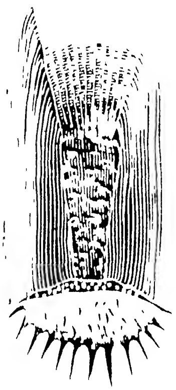


Fig. 9.—Ctenoid Scale—Sole.

The *ganoids* are covered with thick scales containing bony structure, and covered with enamel. Nearly all the species are fossil; an example of two of the recent being the sturgeon and pike (Fig. 7).

In *placoid* fish, the skin is covered irregularly with plate-like scales, which are not enamelled. Most of the species are fossil, but the shark may be taken as a type of one of the living genera (Fig. 8).

In the *ctenoid* order the scales are bony, and often much serrated at their posterior margin, hence the name "comb scales;" there are a few fossil genera of this type, but the majority are living. The illustration given is from the sole (Fig. 9).

The *cycloid* order, again, contains the majority of our edible and fresh water fishes; examples of the order may be taken from the roach, sprat, salmon, and other common salt and fresh water species; the order will be easily known from the posterior margin of the scales being smooth or entire (Fig. 10).

It may be mentioned in passing, that occasionally and under abnormal circumstances, scales having the type of other orders have appeared, though in small number, upon the skin of other genera.

In regard to the structural characteristics of fish

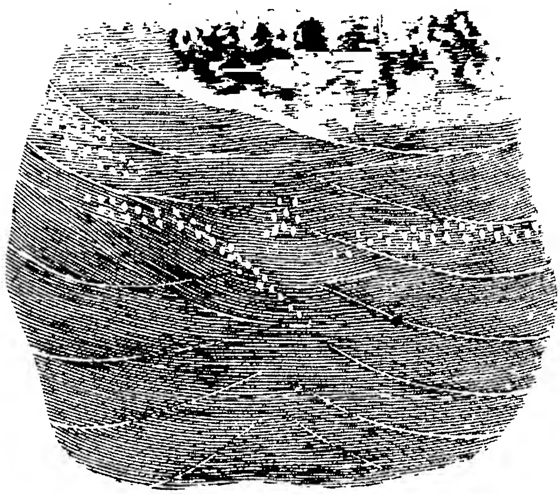


Fig. 10.—Cycloid Scale—Sardine.

scales it will be noticed that each scale consists of really two portions: an inner, which gives the character to the scale from being fibrous in structure, and therefore rules the guiding lines. Covering this is a structure composed of concentric scales: these scales add to the general force of structure given by the under tissue.

Fish scales contain a large percentage of inorganic matter, various salts of lime being generally present, chiefly the phosphate and carbonate of lime (calcium).

AN OLD CONTINENT IN THE ATLANTIC OCEAN.

By Charles Callaway, M.A., D.Sc., F.G.S.

According to the ancients there once existed in the Atlantic Ocean, opposite Mount Atlas, a great island adorned with every beauty and possessing a numerous population. Its princes were powerful, so that they invaded Europe and Africa, but were defeated by the Athenians and their allies. Its inhabitants degenerated into impiety, and the island was in consequence swallowed up in a day and a night. This legend is said to have been related to Solon by the Egyptian priests, and is given by Plato in the "Timæus." It probably had its origin in the existence of the Azores, or the Canary Islands, which may have been visited by the Phœnicians. It is the purpose of this paper to prove that this fable has been far exceeded by the reality; that there once existed in the area now

covered by the North Atlantic an Atlantis of continental size, and of an antiquity compared with which Plato's island is but of yesterday.

Some geologists are of opinion that North America was connected by land with Europe in Middle Tertiary (Miocene*) times. The evidence upon which this theory is based is the resemblance of the existing plant life of North America to that which flourished in Western Europe in the Miocene epoch. The plants are supposed to have migrated from east to west by way of this imagined Atlantic land. It seems extremely unlikely, however, that so great changes in the physical geography of the globe should have taken place within times comparatively so recent. The deeper parts of the Atlantic are from 12,000 to 16,000 feet, and we require very strong evidence to convince us that such enormous depressions have occurred since a comparatively recent geological period. The migration of the Miocene flora may be more easily explained. The land connection between Europe and North America by way of Asia is broken only by Behring's Straits, which are very shallow; and a slight elevation would make it complete. That the migration has been from west to east, across Europe and Asia, receives confirmation from the fact that a flora similar to the North American has been discovered in Japan. It is, therefore, unnecessary to create an Atlantic continent to account for the migration of the Miocene flora. The continent of which it is the purpose of this paper to speak is of incomparably greater antiquity. No traces of it now remain, unless the submarine ridge, which runs down the Atlantic valley in about 50° west longitude, be its denuded foundations. This ridge represents a great mountain range, rising 4,000 feet above the valley to the west, and 8,000 feet above the valley to the east; and reaching to within about 4,000 feet of the surface of the ocean. The Atlantic islands are not in any way connected with this ancient land. They are of volcanic origin, rising steeply out of a deep ocean, and are of comparatively modern date, the oldest strata contained in them being of middle Tertiary age. The destruction of the old Atlantis strikingly illustrates the instability of the land. At an epoch inconceivably remote, the Atlantic rolled as it is rolling now. Then a huge island raised its back above the waters, and, despite the hammering and grinding action of the waves, grew up into a continent, with river systems and great mountain chains. Rain, frost, ice, and carbonic acid, were all the time at work upon its surface, eroding, filing, sawing, dissolving, softening, washing down; till, after it had braved the elements for many successive epochs, it gradually wasted away, broke up into islands, and finally disappeared. The ocean reclaimed its ancient sovereignty, and its shores gradually assumed their present outline.

Two familiar geological principles must be taken as our starting point. The first is that *denudation is equal to deposition.* If a million tons of mud were in a certain time deposited by the Nile on its banks and at its delta, it is evident that a million tons of rock must have been washed down from the regions of the Upper Nile. Or if the sea eat away a million tons of rock from the coast of Norfolk, it is clear that the same weight of sand and mud must be deposited in the adjacent seas. The existence, therefore, of sedimentary strata of a certain bulk proves the former existence of neighbouring land of equal dimensions as certainly as the bottle of wine on your table proves that there is one bottle less in your cellar. A continent deposited means a continent denuded. But we have not only to ascertain the quantity of the material deposited; we have to find out the direction from which it came. This leads us to a second geological axiom:—that *the proximity of land is known by the character of the derived sediment.* A conglomerate, or "pudding-stone," is simply a consolidated pebble-beach; so that, if we find beds of conglomerate, we know that the land from which they were derived must have been close at hand. Sandstones and shales (laminated or bedded clays) have also their distinctive teaching. A river brings down to the sea large quantities of mud and sand derived from the wearing down of the higher land. The particles of sand being heavier than the particles of mud, will sink first, and will form sand-banks in the estuary of the river, or at no great distance from its mouth. The finer portions of the clay will remain suspended for a much longer time; and, if they are drawn within the influence of powerful currents, they may be swept out for hundreds of miles, and deposited in the ocean far from land. Conglomerates, sandstones, and clays (or shales), are thus indices of the distance of the lands from which they are respectively derived. It would be beyond the scope of this paper to indicate the limitations to this statement; it is sufficient for our purpose that it is roughly true. The evidence derived from limestones is rather more complicated. Some limestones are deep-sea deposits; or, at any

* See FRONTISPIECE to "Science for All," Vol. I.

rate, are formed in waters free from the washings from the land. Such is the chalk of our south-eastern counties, which has its modern representative in the calcareous mud which covers the middle depths of the Atlantic. Other limestones are produced by the building up and wearing down of coral reefs; and, though they do not necessarily prove that the land was far distant, are evidences that the sea was free from mud and sand, for the coral zoophytes will not grow in turbid water.

If strata are traced for any distance in their horizontal extension, they are frequently found to pass gradually into sediment of a different character. A conglomerate may graduate into a sandstone, a sandstone into a shale, a shale into a limestone. In each case the land lies in the direction of the former of the two. If a conglomerate pass to the west into a sandstone, the land lay to the east. If a shale graduate to the north into a limestone, the land lay to the south.

The *thickness of strata* must also be taken into account in searching for the direction of the land. In a delta, for example, the beds of sand or clay thin out towards the deep sea. The washings from a coast also follow the same principle. The *thick* end, therefore, of a series of rock beds points in the direction of the land from which the material was derived.

In our present argument we are chiefly concerned with the Palæozoic groups—or the most ancient rocks in which any fossils are found—especially those of the United States, which are very favourable for our purpose, being of great horizontal extent, and comparatively undisturbed. In Western Europe the older groups of rocks cover more limited areas, and are generally much altered, twisted, broken, and dislocated, so as to render their study less satisfactory.

The area in North America to which our study is chiefly directed, is in extent about 1,000,000 square miles, being the great mass of land which lies between the Atlantic and the Mississippi, east and west; and between Canada and Georgia, north and south. In the east the strata are crumpled up into a series of folds, with a north-east and south-west strike parallel to the Atlantic coast-line, and forming the high-land of the Appalachian mountain system. Towards the west those great waves of rock gradually flatten out, so that on the Mississippi the strata lie horizontal. The rocks which cover this area are chiefly Palæozoic, including the formations from the Lower Cambrian to the Carboniferous. We shall study these groups in ascending order.

Commencing with the Lower Silurian, we pass over the formations below the Hudson River group, as their testimony does not bear upon our topic. The *Hudson River* formation in eastern New York is 700 feet in thickness; on Lake Huron it has thinned out to 180 feet; still farther west, in Michigan, it is attenuated to 18 feet. The evidence from the thinning of the beds is confirmed by the change in the character of the sediment. In New York the group consists of sandstones and shales; in Ohio it has become highly calcareous.

The *Oneida Conglomerate* is an Appalachian deposit. In Pennsylvania it is 700 feet thick. It does not extend to the west.

The *Medina Sandstone* is 1,500 feet thick in Virginia and Pennsylvania. Consisting of finer material than the underlying conglomerate, it reaches farther to the west, but thins out in that direction.

Coming next to the Upper Silurian we take first the *Clinton* group. In the eastern part of our area, it consists of shales with some thin beds of limestone; but to the west it is represented by limestones. It stretches farther west than the Medina sandstone. The *Niagara* formation is represented in the Appalachians by shales, which pass towards the west into limestones.

Next in order is the Devonian system, the base of which is the *Oriskany Sandstone*. This deposit is a thick series of sandstones in the Appalachians, but in the State of Missouri it has become a limestone.

The *Hamilton* group in Eastern New York is a sandy deposit with land plants, but westward it gradually passes into a calcareous shale, with limestones. The *Chemung* formation is similar to the Hamilton. In New York it is sandy, in Iowa it is calcareous.

The *Catskill* group is confined to the Appalachian area. In that mountain-chain it is from 5,000 to 6,000 feet in thickness; in the State of New York from 2,000 to 3,000 feet. It consists of conglomerates, sandstones, and shales.

Ascending to the Carboniferous system, we come first to the *Lower Carboniferous* group. In the Appalachian range it is made up of a series of shales and sandstones, 3,000 feet thick. On the Mississippi it is represented by limestones.

The *Millstone Grit* consists of grits and conglomerates. It is absent on the Mississippi.

The *Coal Measures* are 3,000 feet thick in the Appalachian range, and consist of shales and

sandstones. West of the Mississippi they are represented by a limestone.

Fig. 1 illustrates the thinning out of the Appalachian deposits, with their passage into limestones.

From these details we gather two important facts:—First: the strata *thin out towards the west.* Some of the formations are almost confined to the Appalachian range, others stretch some distance to the west, while others reach the Mississippi in an attenuated form. The total thickness of the above group is at least four or five miles in the east, but in the west it has diminished to less than one mile; forming a great wedge, a thousand miles square, the thick side of which is directed eastward. Second: when the strata grow more calcareous, that *transition always takes place westward.* Both of these facts lead to the same conclusion, that the land from which this great mass of rock was derived lay to the east, that is, in what is now the North Atlantic Ocean.

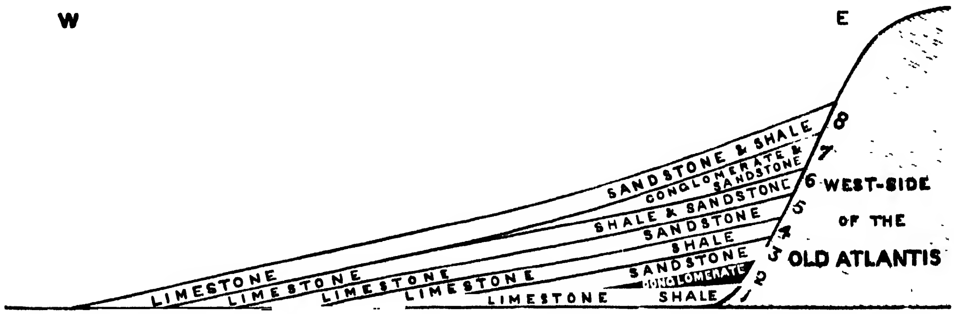


Fig. 1. Deposits formed by the Denudation of the Old Atlantis on the West. (*Scale much exaggerated.*)
(1) Hudson River Group; (2) Oneida Conglomerate; (3) Medina Sandstone; (4) Niagara and Clinton Groups; (5) Oriskany Sandstone; (6) Chemung and Hamilton Group; (7) Catskill Group; (8) Carboniferous Group.

Our next inquiry has reference to the size of this Old Atlantis. We have some rough data for determining this question. We must first ascertain the size of the mass of material deposited. We have seen that it is about 1,000,000 square miles. We shall not exaggerate if we take the average thickness at one mile. This would represent a continent of 1,000,000 square miles in extent, and one mile in vertical elevation above the level of the sea. But the average height of existing continents is less than one quarter of a mile, so that if we assume that measure for the height of our ancient land, we must give it an area of 4,000,000 square miles, that is, 2,000 miles each way.

But in building up our old Atlantis, we have as yet taken into account only the strata deposited on the west. We are not without evidence that some of our European formations were derived from the same source, though the testimony is not so complete, for the reason above stated.

The Silurian and Cambrian rocks of Western Europe are of great thickness. The Lower Cambrian of Shropshire alone is about six miles thick, as may be seen in the Longmynd Hills, near Church Stretton. The Upper Cambrian rocks of North Wales are estimated at 8,000 feet. The Silurian series of Britain can hardly be less than 20,000 feet. The Cambrian and Silurian united will not be over-estimated at a thickness of ten miles. In Scandinavia these systems have become greatly attenuated. Murchison calculated that 30,000 feet of Lower Silurian strata (his Lower Silurian includes the Upper Cambrian of most living geologists) in Britain, were represented by only 1,200 feet in Sweden and Norway. The same author estimated that the Silurian rocks in Russia were probably not a fortieth part of the vertical magnitude of our magnificent British deposits.

The Devonian strata of Britain also thin out considerably towards the Ural Mountains. In Ireland and Britain they are largely composed of sandstones and conglomerates; in continental Europe they are for the most part calcareous.

During the Upper Carboniferous period, land conditions prevailed in Britain; towards Eastern Europe, marine deposits predominated.

The thin end of the Palæozoic wedge in Europe is thus seen to be directed towards the east, and the land from which the strata were derived must consequently have been situated to the west. Thus the Old Atlantis, by means of its rivers and the waste of its coast-line, probably helped to build up lands on both the west and the east. We cannot, however, suppose that deposition took place only on two sides of the Old Atlantis. During the Palæozoic epochs, marine limestones were deposited in several parts of the Arctic regions, so

that an open sea must have spread in that direction, and some of the waste of the old land must have been carried into that sea. The same wearing down of the land must also have taken place to the south, unless, indeed, the Atlantis was part of a great continent which stretched out into what is now the South Atlantic Ocean.

Assuming the Old Atlantis to have been an island, we shall hardly be exaggerating if we conclude that it was at least as large as Australia, which is about 2,400 miles from east to west, and 1,700 from north to south. The denudation of the western side, as we have seen, produced a mass of land as large as Australia; and denudation on the east, north, and perhaps south, should at least double our estimate. I am desirous, however, to err on the side of moderation, and shall be content to make my Old Atlantis the same size as our southern continent.

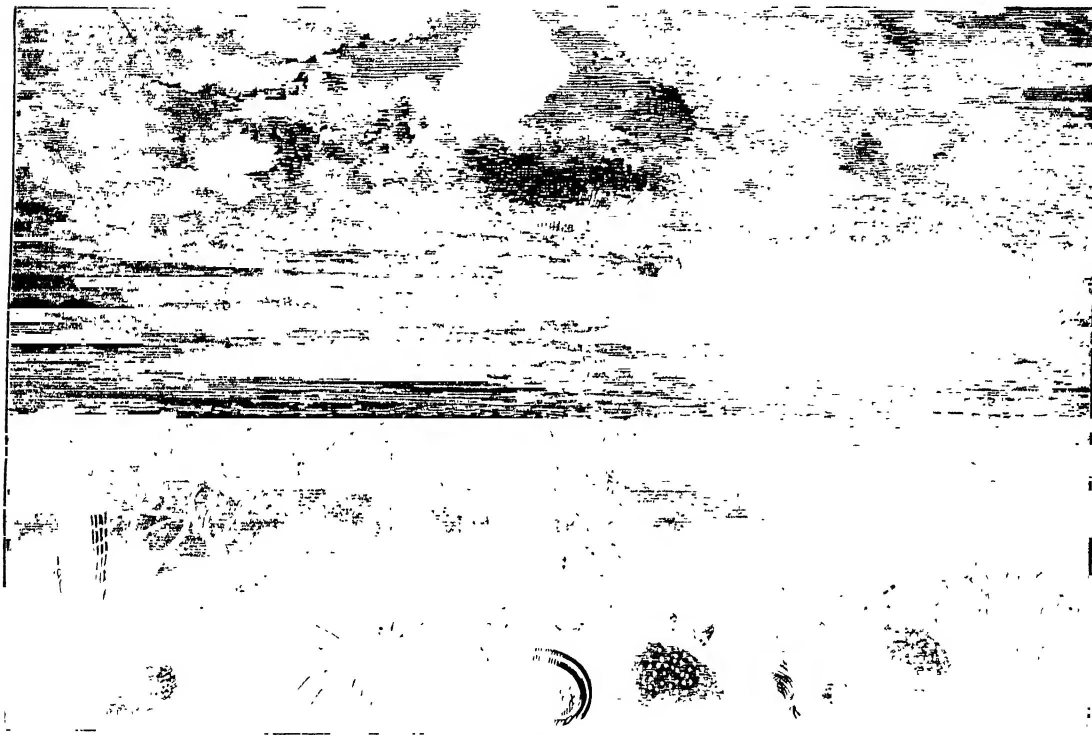


Fig. 2.—Ideal View of Marine Life in the Sea surrounding the Old Atlantis.

We come next to the climate of the Old Atlantis. We can infer this only from what we know of the climate of North America and Western Europe in Palæozoic times. During the Silurian epoch, the same marine animals which flourished in middle latitudes prevailed to within 400 miles of the North Pole, a fact revealed to us by the fossils collected during the Arctic expedition of Sir George Nares. In Carboniferous times, the same assemblage of land-plants extended, with slight modifications, from the Southern States of America to high polar latitudes. Such facts as these teach us that the climate of our northern hemisphere was very uniform, since the distribution of animals and plants is largely dependent upon temperature and other climatal conditions. This equability of climate in ancient times receives strong confirmation from the distribution of plants in the Miocene period, when even such northern lands as Greenland and Spitzbergen supported a luxuriant vegetation of beeches, oaks, maples, planes, walnuts, ferns, magnolias, and other plants of temperate climes. If the climate of the earth was so free from extremes in times comparatively so recent, we can the more readily believe that such was the case in a more remote epoch. During the Carboniferous period the predominant forms of vegetable life were tree-ferns, gigantic horse-tails, lycopodiaceous plants, and conifers; the balance of probability

arising from this flora being in favour of a warm, moist climate. If, as some eminent authorities are of opinion, our sun is cooling down, it must have had greater heating power in such ancient times as those we are considering. Professor P. Martin Duncan* is of opinion that our earth is gradually losing its atmosphere as the moon has already lost hers. If this be so, our atmosphere in Palæozoic ages must have been denser than at present. This augmented density would tend to produce a higher temperature, our Alpine experiences proving to us that the cold increases with the rarity of the air. All the evidence we can gather tends to the same conclusion—that the climate of the Old Atlantis was warmer than that of our present globe in the same latitudes.

The life of our Atlantis next engages our attention. On this subject we can speak only so far as discovery has led us, and new revelations of fossil life may modify our conclusions. Great changes of course took place in the long succession of epochs during which the Old Atlantis supported animals and plants; and I prefer to speak only of the later periods of its existence, because it was then that its forms of life reached their richest development. We know something of the fauna and flora of neighbouring lands during the Carboniferous period, and it is fair to infer that the life which flourished in the Old Atlantis was not very

Fig. 3.—Calamite Restored. (30 to 40 *feet high.*)

Fig. 4.—Lepidodendron Restored. (40 *feet high.*)

* Presidential Address to the Geological Society, Feb., 1877.

different from that of Western Europe and eastern North America. The king of our ancient continent was not of very distinguished family. He is named *Hylonomus* (Fig. 5). He belonged to the reptiles, and bore some resemblance to a lizard. There is, indeed, some doubt whether he could claim reptilian rank, as he had close affinity with the amphibians, who are fish during the earlier part of their life, and reptiles only in their riper years. This creature, so far as is at present known, was the highest organisation of these early epochs. No bird made the luxuriant forests of tree-ferns and club-mosses

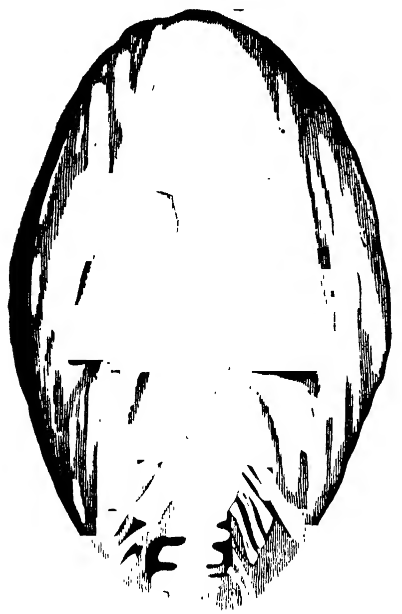


Fig. 5.—Skull and Shoulders of *Archegosaurus minor*, one of the Ruling Race in the Old Atlantis.

vocal with its music, or left the trifid imprint of its feet upon the sands of the shallow estuaries. No mammal, even so lowly as a kangaroo or a duck-billed Platypus, still less, so exalted as a lion, or horse, or a monkey, hunted over the plains or sported in the tropical sun. The real monarchs of creation were the Labyrinthodonts, so named from the complex and beautiful structure of their teeth, in which the enamel was arranged in folds resembling the convolutions of the human brain. These belonged to the *Amphibia*, and some of them still retained in their later reptilian life the traces of their fish origin, such as the arches which contained the gills, and the cartilaginous backbone. Some of them were of gigantic size, such as *Baphetes* and *Anthracosaurus*, and must have been mayors of the palace to the more dignified but feebler *Hylonomus*. *Hylonomus*, however, was not one of the last scions of a decaying race; he was probably one of the founders and forefathers of the great saurian* dynasty which ruled the world in Mesozoic times, when the Old Atlantis had sunk beneath the waves. Snails made their first appearance in the later ages of our ancient continent, being represented by forms resembling the modern *Helix* and *Pupa*. Insects appear to have been tolerably abundant, and were represented in most of the present orders; but some of the earlier types were "synthetic,"—that is, combining peculiarities of structure now found only in different groups. We have insects resembling May-flies, beetles, cockroaches, crickets, and locusts. The myriapods are very peculiar, with segments divided by cross sutures. Amongst the spiders is a curious scorpion, with its twelve eyes disposed in a circle. The plant-life of the later Palæozoic periods—which has been already noticed†—is their most conspicuous feature. Ferns are very abundant, some of gigantic size. Calamites resembling enormous horse-tails (*Equisetum*) grew in dense brakes on low, moist flats. The fruit was a long cone or spike. Some were more than twenty feet in length (Fig. 3). *Lepidodendron* was probably a lycopod, but of giant dimensions, reaching in some cases a length of fifty feet or more. The bark was covered with diamond-shaped scars, the leaves were slender and pointed, and spore-cases were formed in spikes at the ends of the branches (Fig. 4). *Sigillaria* had its bark covered with seal-like scars, and attained equal dimensions with any of the preceding. Numerous other genera abounded, but it is doubtful if, amidst this prolific vegetable life, any flowering plants existed. Many of the types seem to have combined peculiarities now found only in widely-separated groups. Fish were abundant in the rivers and seas of the Old Atlantis. They were all of them "heterocercal,"—that is, with the back-bone prolonged into the upper lobe of the tail—a peculiarity possessed by comparatively few modern fishes. Most of them were ganoids, the body being covered by large, strong, shining plates. In Fig. 2 we have a representation of the marine life of this ancient period.

Such were, then, the denizens of this ancient continent. They lived and died, and their sepulchres are with us to this day in the form of the hollow trunks of fossil trees, or of beds of ironstone, clay, or sandstone. The very types to which

* "Science for All," Vol. II., p. 137.
† "Science for All," Vol. I., p. 89.

some of them belonged are gone, and since their time new types have come into being, in their turn to give place to still higher forms. Of the mode of life of these antique creatures we can form a rough idea. The glory of their existence was, doubtless, to conquer and to devour. Suffering and death was the common lot. The great alternative of life was to kill or to be killed. But this seemingly wretched state was not all evil. The perfection of the animal kingdom was to be attained through suffering and conflict. Had these ancient beings been provided with the means of idleness and easily obtained supplies of food, higher types might never have been produced. Through the immeasurable epochs, amidst the upheaval and decay of continents, with types of life coming slowly into being and as slowly departing, the races of the world were being elaborated into higher forms, till man appeared as the crown of the organic world.

HOW ELECTRICITY IS PRODUCED.

By William Ackroyd, F.I.C., etc.

Many a smoker is proud of his meerschaum pipe, with its mouth-piece of amber, and if the latter be of genuine quality, we would ask him to put it for a few moments to a use that will not be objected to even by the most severe of anti-tobacconists. Take the dry mouth-piece, and rub it rapidly on a piece of silk, and now bring it close to a few small bits of paper and hair that have previously been laid on the table. The paper and hair jump up and adhere to the amber. Rubbing the amber has evolved the power now manifested. This was about the only experiment of the kind known to the ancients. The reign of Elizabeth saw an accession of new facts. In the year 1600 was published the *Tractatus de Magnete*, by Dr. Gilbert, of Colchester, wherein he gives a list of substances which he found to possess the same property as amber; and Gilbert named the science. He called it electricity, from *electron*, the Greek word for amber. Thus the reign celebrated for the perfection of the drama by the immortal genius of Shakspere, and for the new method of philosophy by Bacon, was not less remarkable as that which saw the advent of a science whose great results in telegraph and telephone, electric light and microphone, we are witnessing in the nineteenth century.

The ways in which electricity may be produced seem legion. The pen I write with, and the holder that clasps it, are of different metal. The heat of my finger and thumb grasping the portions in contact is sufficient to produce a current of electricity from one metal to the other. There goes the sound of a locomotive whistle, echoed and re-echoed from the neighbouring hills. As the blast of steam was issuing from the nozzle to generate the sound, electricity was produced. At each tap of my foot against the carpeted floor electricity is evolved, and it is probably generated within every living organism.

Several ways of producing electricity have been described in these pages,* and of these perhaps the frictional method is of most interest to the ordinary reader. Respecting this way of generating electricity, the reader knows that the thing rubbed has a different kind of electricity produced on it from that obtained on the rubber; that these two electrical states are antagonistic to each other, and so related that a body is never electrified in one way without another body being electrified in the opposite way, and to the same extent. Thus, when glass and silk are rubbed together, they are both excited, and the electricity generated on the glass is of an opposite kind to that produced on the silk pocket-handkerchief. We agree to call the electricity produced on the glass, under these circumstances, positive, and that excited on the silk negative, electricity. The algebraic signs, plus (+) and minus (−), are used to denote these states.

In the following list all the substances going before are positive when rubbed with any that come after—*e.g.*, when glass is rubbed with cotton the former is positive and the latter negative:—Fur, flannel, ivory, quartz, wood, shellac, resin, glass, cotton, silk, the hand, sulphur, vulcanised caoutchouc, ebonite, caoutchouc, gutta-percha.

After Gilbert's time the next progressive step, historically, was the employment of machinery to perform these rubbing operations, and to this end many instruments have been invented. Fig. 1 is an illustration of a plate machine, often used when great quantities of electricity are required. The

* "Science for All," Vol. I., p 45.

large plate of glass (P) is made to rapidly rotate by means of the handle seen in the cut to the left. The plate is grasped by double rubbers at F F, and the electricity generated on the glass is gathered by the row of points on either side, which are in communication with

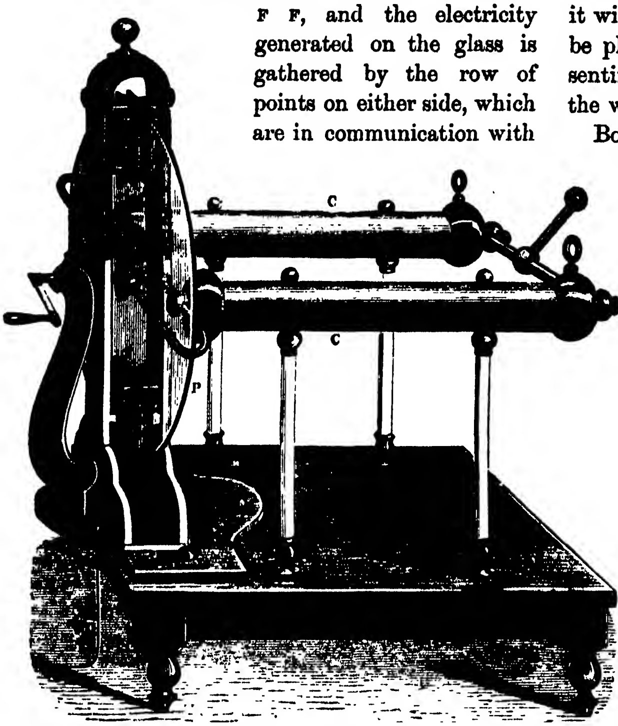


Fig. 1.—Plate Electric Machine.

the insulated conductors (C C). It will be observed that in this, and all such machines, we are simply adopting mechanical means to perform on a larger scale the simple rubbing experiment with which we started; and as we afterwards varied the nature of the rubber and thing rubbed, so here we could replace the plate of glass by ebonite and other substances, and for rubbers we might employ a number of bodies found most suitable by actual experiment.

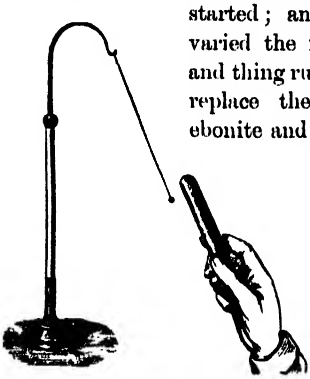


Fig. 2.—Electric Pendulum.

It will be necessary for us to know one or two curious facts about this electrical state of bodies. Substances that are excited attract those that are in their ordinary state, and conversely unelectrified bodies attract those that are electrified. In the amber experiment, an electrified body is seen to attract those which are not electrified; and the following experiment illustrates the converse:—Take a piece of brown paper, and when hot rub it with a clothes-brush. If now the excited paper be placed near the wall, it will adhere to it, presenting us with an example of an unelectrified body, the wall, attracting paper that is electrified.

Bodies that are in the same electrical state exhibit a remarkable antipathy towards each other; positive shuns positive, and negative equally repels negative. We may here profitably repeat the experiment with the electric pendulum (Vol. I., p. 45). When an excited glass rod is presented to the unelectrified pith ball, the latter is attracted; as soon, however, as ever they have come in contact, and the pith ball has become in the same electric state as the glass rod, the pith ball flies away: they repel each other (Fig. 2). It will be seen therefore that, if we can succeed in similarly electrifying two pendulous strips of metal (Fig. 3, *a b*) attached to a rod (R), they will fly apart, taking the positions of the dotted lines (*a′ b′*). This fact is utilised in the gold-leaf electroscope, or electricity detector, a useful and handy little instrument for ascertaining some of the qualities of the electrical condition of matter.

We shall proceed to describe how one of these instruments may be made in a cheap and efficient manner. Clean and dry well a glass flask, fit it with a cork, and bore a hole through the cork to enable it to hold tightly a piece of glass tube about an inch long. Now cut out a zinc disc, about an inch and a half in diameter, or take a penny piece instead. Drill a small hole through the centre, and solder in it a straight brass wire nine inches long. Drill a hole near the edge of the disc. Now take the glass tube, clean and warm it, and fill with clean shellac. Afterwards warm the brass wire, and push it through

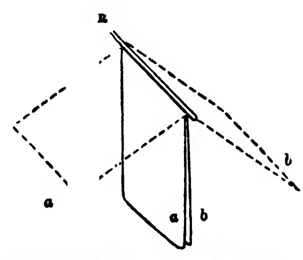


Fig. 3.—Action of Leaves in the Electroscope.

the shellac. To ensure having an efficient instrument, this must be done well and carefully, as there must be no dirt or moisture present. Fix the tube now in the cork, and cover the outside of the tube with more shellac. Clean the wire, and bend its lower end round into a hook, with the horizontal part

about three-quarters of an inch long, and flattened to receive the gold leaves. The reader may now cut out two strips of Dutch metal, say three inches long and half an inch wide. Then, gumming each side of the hook, the leaves may be taken up, shaded from air-currents, and placed in the flask. We now possess an instrument made after the directions supplied by the Physical Department at the Science Schools, South Kensington: easy to make, and serviceable when made. It is seen in Fig. 4.

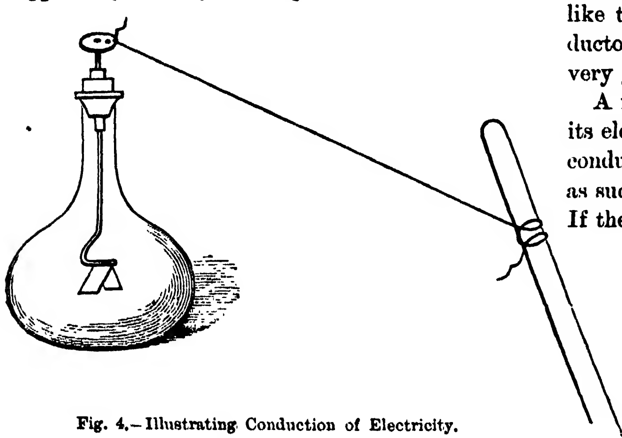


Fig. 4.—Illustrating Conduction of Electricity.

We have produced the electrical state by rubbing together amber and silk, and silk and glass, and doubtless electricity is produced in every operation where friction comes into play between two dissimilar bodies. It is, however, sometimes difficult to detect it, because of the other qualities these bodies possess which are opposed to its marked manifestation. If one end of a long rod of copper were inserted in the fire, we should soon be sensible of the fact that the end we were holding was becoming hot, for the rod would be conducting heat along its substance to the hand. If now the heated copper were removed from the fire, and placed in contact with a larger mass of cold metal, we should find, after a little while, that the copper had become cold again. It would be difficult, then, to keep a metal in a heated condition under these latter circumstances, because of this quality of conductivity which metals possess. As bodies behave with respect to heat, so to a certain extent is it the case with regard to electricity. Attach a copper wire to the disc of the electroscope, winding the other end round a glass rod that now may be excited (Fig. 4). The electricity of the rod is conveyed along the wire to the electroscope, and its leaves diverge. The conductivity of the wire may be shown again in this way. Communicate a charge of electricity to the electroscope by bringing an excited body in contact with the disc, and, whilst the leaves are in a diverged position, touch the disc with one end of the copper wire: the leaves at once collapse. The wire has this time conducted the electricity away. By using a number of substances for these experiments, such as a loop of silk, ordinary twine, &c., it will be ascertained that some, like the silk, are, comparatively speaking, non-conductors, whilst others—as, *e.g.*, metal wires—are very good conductors.

A metal bar that has been electrified soon loses its electricity if in contact with anything that will conduct it away. The hand, for example, will act as such a conductor, especially if moist with sweat. If the metal, however, be surrounded by a sheet of india-rubber, the electricity does not so readily escape. Like an island surrounded by water which prevents communication with the mainland, so now our bar of metal is surrounded by a non-conducting substance which prevents the electricity from escaping. A body situated thus is said to be *insulated*, and the substance surrounding it is called an *insulator*. This division of substances into conductors and insulators arose from the experiments of one in humble circumstances, Stephen Grey, a pensioner of the Charterhouse. In 1729 he discovered electric conduction. After a series of experiments, some successes and many failures, he made the following discovery:—An ivory ball was attached to a piece of pack-thread and the other end tied to a long glass tube. The ball was then hung from a balcony. Upon rubbing the tube, he found that the ivory ball below attracted light bodies. The electric state of the tube had plainly been conveyed along the string to the ball.

His next attempt was to ascertain whether this state could be conveyed horizontally, and with this view, he fixed a cord to a nail in the ceiling. Through a loop in the cord he inserted his pack-thread with the ball at the end of it, and retired with the tube to the other end of the room. Upon rubbing the tube the ivory ball refused to attract light bodies. A silk string was next employed instead of the cord to hold up the pack-thread. Now the ivory ball did attract light bodies. Wires of fine brass and iron were next employed as supports with the same results as when the cord was used, but when the pack-thread was supported by the silken string he was able to convey the electric state through 765 feet. The brass, iron, and cord are conductors, the silk comparatively a non-conductor or insulator.

Great friction is not always necessary to evolve electricity. A single stroke of one metal against another will generate it, although it is instantly dissipated by conduction and only by extremely delicate means can we ascertain the fact. When I draw my thumb-nail across a piece of india-rubber electricity is produced, and here we may detect it by availing ourselves of the comparative non-conductivity of the india-rubber. Wherever the thumb-nail has been drawn, there electricity has

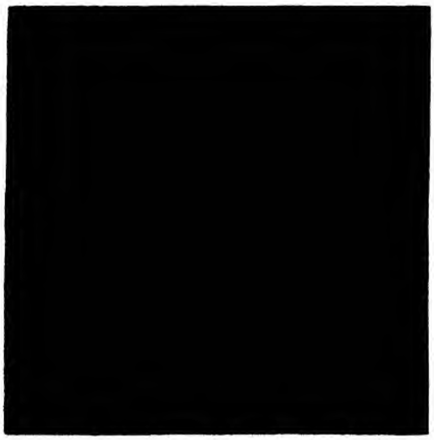


Fig. 5.—How it may be shown that Electricity is produced on India-rubber by Friction of the Thumb-nail.

been generated, which is so long in being conducted away that we may make use of an exceedingly simple method of proving it that was devised by Dr. F. Guthrie, Professor of Physics at the Royal School of Mines, with whom the author had the honour of making many experiments in this way. A mixture of powdered brimstone and red oxide of lead, both very dry, are tied up in a muslin bag. When the bag is shaken the powder is sprinkled out with the ingredients in opposite electrical states, so that the electrified track on the india-rubber only selects that ingredient which is of opposite electricity to itself, and repels the ingredient which is of like electricity. The result, then, is this: after sprinkling the powder over the india-rubber a red mark is seen wherever the thumb-nail has been drawn over it. The track has drawn to it the red oxide and repelled the similarly electrified yellow sulphur. Many substances may be found which, when stroked along the india-rubber make a mark that takes to itself the yellow sulphur and repels the red oxide. A number of other mixtures may be used instead of the brimstone and red oxide, but whatever the mixture, it is necessary that all the apparatus be warm and dry (Fig. 5).

This very readiness with which electricity is produced is sometimes a source of intense annoyance to electricians when employed in making measurements with very delicate apparatus. An interesting example of this is given by Sir Charles Wheatstone.*

Wheatstone was experimenting with a measuring instrument, but got so far astray that he was persuaded there was some cause at work of which he was ignorant. He commenced to look for it, and found that it was the electricity generated by treading on the rug in the room where he was working. He tells us that "The most essential condition appears to be that the boot or shoe of the experimenter must have a thin sole and be perfectly dry; a surface polished by wear seems to augment the effect. By rubbing the sole of the boot against the carpet or rug, the electricities are separated, the carpet assumes the positive state and the sole the negative state; the former being a tolerable insulator prevents the positive electricity from running away to the earth, while the sole of the foot, being a much better conductor, readily allows the charge of negative electricity to pass into the body" (Fig. 6).

Wheatstone further remarks: "At the Meeting of the British Association at Dublin, in 1857, Professor Loomis, of New York, attracted great attention by his account of some remarkable electrical phenomena observed in certain houses in that city. It appears that in unusually cold and dry winters, in rooms provided with thick carpets, and heated by stoves or hot-air apparatus to 70°, electrical phenomena of great intensity are sometimes produced. A lady walking along a carpeted floor drew a spark one quarter of an inch in length between two metal balls, one attached to a gas-pipe, the other touched by her hand; she also fired ether, ignited a gas-light, and repelled or attracted pith balls similarly or dissimilarly electrified. Some of these statements were received with great incredulity at the time, both here and abroad, but they have since been abundantly confirmed by the Professor himself and by others."

Fig. 6.—Wheatstone's Experiment.

The union of the two electricities is accompanied

* "Proceedings of the Royal Society," Vol. XVIII., pp. 330—3; and p. 216 of "Wheatstone's Scientific Papers," reprinted by the Physical Society, 1879.

by a spark. This may be seen by briskly rubbing a cat's back in a dark room, when under favourable

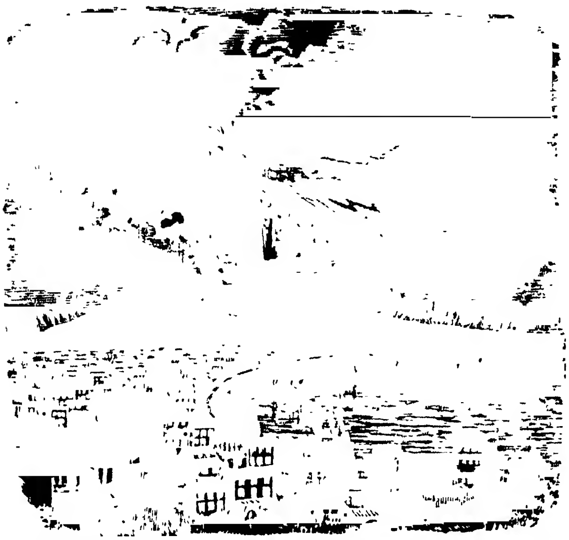


Fig. 7.—Electricity produced by the Discharge of a Volcano. (Vesuvius in 1822.)

atmospheric conditions a slight crackling sound will be heard, and minute sparks will be seen. The electricity generated on the hand is of a different kind to that generated on the cat's fur, they therefore unite when they have accumulated sufficiently to overcome the resistance of the intervening air. In nature we get a fine display of sparks in the aurora borealis (Vol. II., pp. 1–6), and in the various kinds of lightning (Vol. I., p. 266). All these remarkable electrical effects can now be scientifically explained, as the reader will find in the papers just referred to, and we are no longer driven to the myths that were invented by the ancients to satisfy their keen longing to know what all the varied phenomena of nature were due to. As the lightning played round a volcanic crater in those days, a Roman youth would ask, "What causes those blinding flashes?" and the Roman father we can fancy replying, "It is Jupiter hurling away his thunderbolts, *O fili mi!*" As with this, so with other appearances, and Virgil expresses their wants when he exclaims: "For myself, may the lovely Muses first, above all else, take me to themselves and show me the paths of heaven and its stars, the various eclipses of the sun and labours of the moon, from whence the earthquake springs, by what force it is that deep seas learn to swell and burst their barriers, and again of themselves sink back into their place, why winter suns make so much haste to dip in the ocean, or what obstacle it is that clogs the course of the lingering nights."

We now have our explanations of these appearances, explanations that are the outcome of decades of thought and experiment, and the lightning flashes above the summit of Vesuvius we refer rather to the friction between the newly-condensed water-particles, air, and ashes (Vol. I., p. 265), than to Jupiter (Fig. 7).

High-pressure steam issuing from a small orifice generates electricity. This is the means adopted in Armstrong's hydro-electric machine to produce powerful effects (Fig. 8).

The machine consists essentially of a steam-boiler, with the ordinary accessories of furnace, water-gauge, safety-valve, &c., and the boiler stands upon supports which will not conduct away the electricity. After the steam has acquired sufficient pressure, the tap C is turned on, and the steam then issues from the jets at A. These jets are made of boxwood, and their construction will be understood from an inspection of the section at M. It will be seen that a bent piece of metal causes the steam to strike against the sides of the mouth-piece, and it is moreover partially condensed before it escapes by the box B, which is filled with cold water.

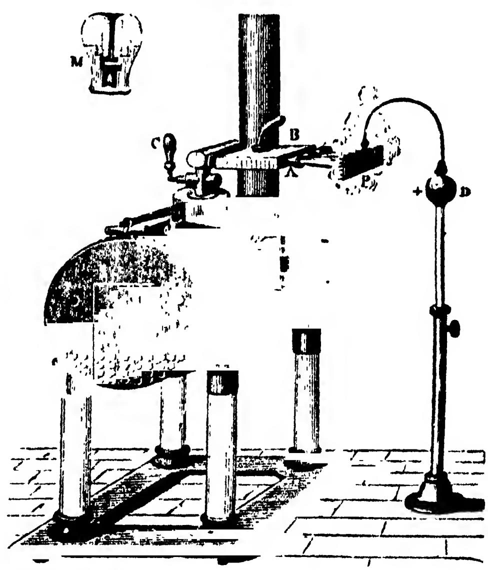


Fig. 8.—Armstrong's Hydro-Electric Machine.

The issuing steam is found to be highly charged with positive electricity, which is collected by a number of points at P, supported on an insulating

stand, and connected with the prime conductor D. The boiler becomes very highly charged with negative electricity. The electricity generated seems to be due to the friction exercised between the sides of the narrow tubes and the small drops of liquid water carried in the stream of steam. Faraday has shown that evolution of electricity ceases if acid be added to the water in the boiler.

So far we have dealt with a kind of electricity that we have produced by friction, and which we may therefore term frictional electricity. We may, however, generate electricity in some other ways, electricity which differs in many important respects from that we have hitherto obtained. But first let us enter into a point of similarity. Suppose that two insulated balls of zinc and platinum contain different kinds of frictional electricity. They are joined together by a metal wire, W. Electricity now flows along the wire from the positive to the negative, and from the negative to the positive. During the short period of electrical equalisation the connecting conductor exhibits peculiar qualities not possessed by it under ordinary circumstances. For convenience, we agree to say that the wire is traversed by a current of electricity, and the direction of this current is regarded as that in which the positive electricity flows.

Two different metals, zinc and platinum, are dipped into acidulated water (Fig. 9). It is found that at their free outer ends the zinc is negative and the platinum positive, and if joined by the wire, W, we get, as before, a flow of electricities in opposite directions, though we speak of the direction of the current as that in which the positive flows. The current in this experiment is called a voltaic current, because the action here described was discovered by the celebrated Italian, Alessandro Volta. Now,

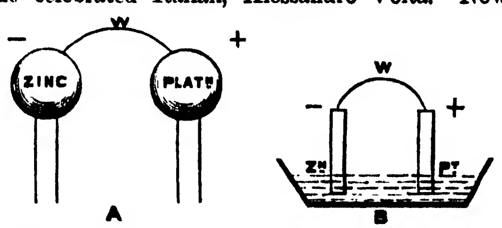


Fig. 9.—Comparison of Frictional and Voltaic Electricities.

wherein do these two kinds of electricity, frictional and voltaic, differ? We shall not attempt to convey an idea of their points of difference by a vivid analogy that would soon be strained; we think it better rather to give a simple statement of facts. A word or two, however, as to an instrument we shall have to use. We have employed the electroscope to detect frictional electricity; we require an instrument called the *galvanometer* to detect a current of voltaic electricity. If the wires which come from the zinc and platinum of a voltaic battery (*i.e.*, a series of such electricity producers as we have represented in Fig. 9, B) be joined to a brass rod, N S (Fig. 10), having under it a magnetic needle (*a b*) delicately poised, it will be found that the needle, which before joining up the wires was at rest and parallel to the bar N S, no longer keeps its position, but swings round through an arc of a great many degrees. This is known as Œrsted's experiment, and it is utilised in the galvanometer.

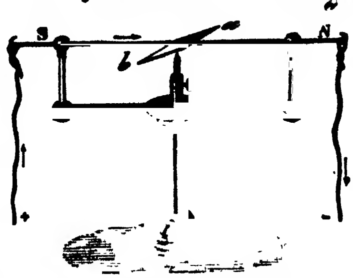


Fig. 10.—Œrsted's Experiment.

This instrument (Fig. 11) consists simply of a coil of covered wire, D, through which the current can be sent by connecting the wires from our battery to K and H. The needle *a b* seen in Fig. 11 is one of a pair arranged as in Fig. 12. The convenience of the latter arrangement will be evident after a few moments' thought. The needle *a b* (Fig. 12), if alone, would persist in pointing north and south, but with a second magnetic needle fixed to it with its poles reversed (*b′ a′*), this tendency of *a b* is neutralised if they both be of the same strength, and the compound needle will settle in any position. Such a needle we may therefore turn to zero on the graduated scale of the galvanometer, and there it will remain until, upon sending a current of voltaic

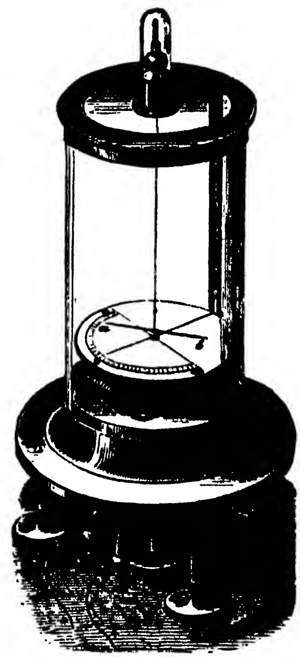


Fig. 11.—Galvanometer.

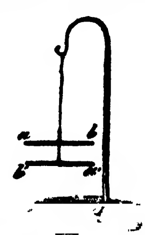


Fig. 12.—Compound Needle for Galvanometer.

FIG. 13.—THE ELECTRIC EEL (*Gymnotus electricus*)

electricity through the wires at K and H, it swings round through an observable number of degrees of arc, showing us, within certain limits, the strength of the current.

There are many simple ways of generating the voltaic electricity. I stick a knife and fork of different metals — say the former of steel and the latter of silver —into an orange. Upon connecting the knife and fork with the galvanometer by means of wires we get at once a deflection of the needle. It is produced in a similar manner in a great number of culinary operations.

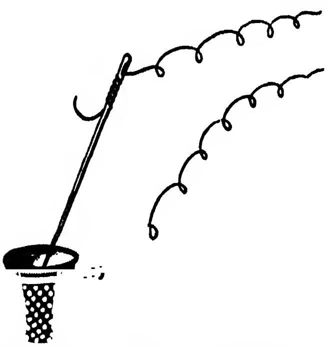


Fig. 14.—Needle and Thimble Source of Voltaic Electricity.

Here is a neat little experiment (Fig. 14). Pour some vinegar into a silver thimble, and now by wires connect the needle and thimble with the galvanometer. Upon placing the needle in the vinegar, taking care that it does not come in contact with the silver, the galvanometer needle swings round with violence. With this tiny apparatus sufficient electricity is generated to traverse the Atlantic cable and give very distinct signals in America!

Now for the relation existing between frictional and voltaic electricity. The current of voltaic electricity generated in the thimble will deflect a magnetic needle after passing through thousands of miles of wire, whereas the same amount of deflection cannot be obtained with a great number of turns of a large plate electric machine. But, on the other hand, this plate machine will generate frictional electricity that can jump over an interval of many inches of air in producing a spark, whilst the current from an exceedingly strong voltaic battery could only jump over an interval of about the one-thousandth of an inch. It will be seen, therefore, that so far as this jumping over an interval of air is concerned, the frictional is much stronger than the voltaic current; it possesses very much more of that force technically termed *electro-motive* force. When we compare their effects on the magnetic needle, the frictional current is much the weaker of the two; and the voltaic is said to exceed the frictional in quantity. Faraday estimated that the quantity of electricity generated by the chemical action of four grains of zinc on a single grain of water to be equal in quantity to the frictional electricity of a powerful thunderstorm.

Physiologists sometimes try a very curious experiment. One of the wires leading to a galvanometer is brought in contact with the freshly-cut end of a nerve, and another wire leading to the same galvanometer is made to touch the outer surface of the nerve. There is an immediate deflection of the needle. Facts of this kind have made many people regard the body as a complicated producer of electricity, the nerves, like the insulated wires to and from our galvanic batteries, serving to conduct the electricity to and from the great central nervous organ. A deflection of the galvanometer needle may be obtained by bringing its two wires, the one into contact with a transverse section of the optic nerve, and the other into contact with the transparent horny front of the eye, and it is a most remarkable fact, made out by the investigations of Holmgren in Sweden, and by Dewar and McKendrick in this country, that the amount of the deflection *varies under the influence of light.* About three years ago, Siemens, in a lecture given before the Royal Institution, tried to imitate the behaviour of the eye in this respect. Crystalline selenium is a better conductor under the influence of light than it is in the dark. Its conductivity likewise varies for the different kinds of light—red, blue, green, &c. In Siemens' artificial eye, therefore, the retina was represented by a thin plate of this sensitive selenium, and the source of electricity was an ordinary battery, the sensitiveness being represented by a galvanometer. On opening

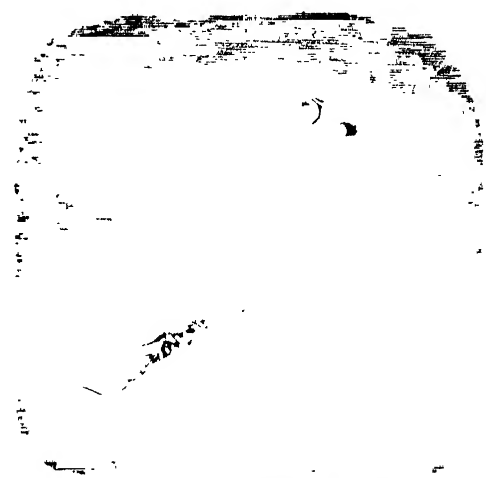


Fig. 15.—The Torpedo (*Torpedo vulgaris*).

the eyelids of this artificial eye, and admitting light from a white illuminated screen, a strong deflection of the galvanometer needle was observed. A black screen gave hardly any deflection, a blue one a greater, and a red a much greater, but still short of that produced by the reflected white light. The eye was thus sensitive to light and colour, and an imaginative scientist would not scruple to regard the galvanometer as a sort of brain, the wires and battery as the nerves and body, of an artificial organism entirely under his control.

The torpedo (Fig. 15) and electric eel (Fig. 13) possess an electrical apparatus which they discharge at will. The shock they communicate to any animal with which they come in contact is so severe that, on the testimony of Humboldt, two horses have been killed in five minutes when exposed to the attack of the electric eel. How the torpedo and eel produce such quantities of electricity we cannot tell, and must therefore leave these living electric machines, and betake ourselves to the description of other means of producing electricity that we can keep more in hand.

Electricity may be generated by the direct agency of heat. Seebeck in 1821 discovered that if two bars of metal be joined together, and heat applied to the point of junction, an electric current will be produced. The following is an excellent method of illustrating the fact (Fig. 16). A compass needle,

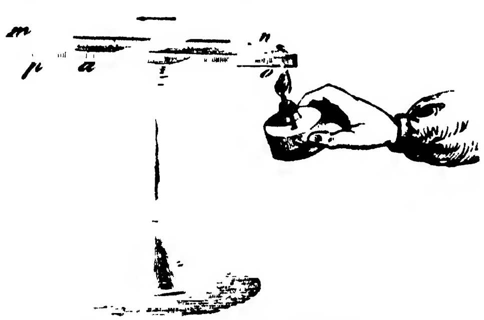


Fig. 16.—Thermo-electric Experiment.

a, is balanced on a point that rests on the plate of bismuth, *o p*. Over the plate of bismuth a strip of copper, with its ends bent down, is so placed and soldered that the needle may freely move. The bars rest on a stand, and the apparatus is arranged so that the needle is parallel to the bars. Upon heating the end *o* with a spirit lamp, a current of electricity is generated, and the needle is accordingly swung round. By applying something very cold to the end *m*, as, for example, a lump of ice, the deflection of the needle will be increased. Such an arrangement of two metals is called a thermo-electric couple (Fig. 17).

The two metals employed in this couple are copper and bismuth. We might, however, have employed any two dissimilar metals, as, for example, iron and zinc, copper and antimony, tin and brass, &c. We find, however, the strength of the electric current in each case to be different, and in making effective couples of course such metals are chosen as give the best current with a given source of heat.

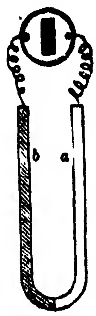


Fig. 17. Thermo-electric Couple of Antimony and Bismuth (*a*, *b*).

The amount of electricity obtained with one couple is increased by having a series of couples bound together. For example, a single bismuth and antimony couple which would give a good deflection of the galvanometer needle, is joined with a lot more such couples, as in Figs. 18 and 19. Such a bundle of couples is called a thermo-electric pile, and is exceedingly sensitive to minute differences of temperature. With such a pile, the heat of the hand several inches away is sufficient to give a deflection of the galvanometer needle. The thermo-electric pile is therefore a delicate instrument of research, and has been usually employed in investigations of heat. Very large piles are now being constructed, which only require a gas jet lighting under them, and they then furnish sufficient electricity for very many useful purposes.

Fig. 18. Construction of a Thermo-electric Pile.

Science is ever interesting itself in two extremes, the infinitely small and the infinitely great; ever trying, in fact, to penetrate into those depths of Nature that are beyond the ken of our unaided senses. With the microscope she has revealed new worlds of minute life, and with the telescope has penetrated into those far-off regions where other suns and other planetary systems exist. And now she leads us to the two electrical extremes, where, on the one hand, currents are produced that are too minute nearly to detect, and, on the other, so large that nature herself is nearly outstripped.

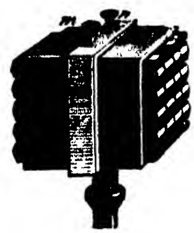


Fig. 19.—Thermo-electric Pile.

I sing a note into the telephone. A small portion of the energy I have expended is converted into vibrations of the telephone plate. The magnetism of the bar within a coil of wire is rapidly varied,

and an exceedingly minute current of electricity is produced, which may be conducted along miles of wire to do the work of vibrating a similar plate at the other end. The current generated is so small, that for a long time no means could be found of determining whether a current was sent along or not. A peculiar galvanometer in the hands of Mr. Page demonstrated the fact. This is one of our electrical extremes.

Fig. 20. -Faraday's Experiment.

The test that we have employed for current electricity has been the deflection of a compass needle. Think well over the fact. What subtle power invests the wire through which this electricity is passing, that it shall cause the magnetic needle to move? The more we think over it, the more we become lost in wonder, and the only practical outcome of our thoughts is the question: Since a current of electricity produces motion of the magnet, will the converse hold good, *i.e.*, will motion of a magnet induce a current in a coil of wire? Faraday answered this question in 1831 by showing that a magnet is able to produce a current of electricity. Coil on a bobbin (Fig. 20) about twenty feet of insulated wire, *i.e.*, wire which is covered with a non-conducting substance like gutta-percha. Connect the ends (*f f'*) with a galvanometer. If now a powerful magnet, A B, be quickly inserted inside the bobbin, a deflection of the needle will be observed, and a deflection in the opposite direction will be observed again when it is withdrawn. Ponder well over this result. We generate electricity by the motion of the hand holding a magnetised bar, and then this electricity traverses a long conducting wire, maybe miles in length, with lightning velocity, and makes a needle move at the other end. In short, we produce electricity by mechanical motion, and then a great distance away reconvert this electricity into mechanical motion again. Can we doubt that a man with the genius of a Watt, with this fact plainly before him, would devise means of generating great quantities of electricity, and reconverting it economically into the movements of machinery; and seeing that we have not one, but many such men, who are now keenly bent on effecting this end, may we not hope that the problem will be solved ere long—that the vast stores of natural energy running to waste in falls like those of Niagara, may be converted into electricity, and conveyed by conductors to towns and villages miles away, to be utilised in the factory and workshop? This is our other extreme. And now the dream of the electrician, which may be, like Pharaoh's concerning the fat kine, an augury of future events, is the utilisation of wind, stream, and torrent to produce electricity, which may then be transmitted to distant business centres, there to replace the steam engine and provide against that evil time, the day of the lean kine, when all our coal-fields shall be burned up.

A SOAP BUBBLE.

By John A. Bower,

Science Master, London Middle Class School, etc.

A BEAUTIFUL but a fragile thing is a "soap bubble." It is something also with which most of us have had to do. For in childhood, how many of us have spent hours and hours over this pretty delicately-coloured toy, and wondered, perhaps, where the beauty of form and colour came from; or, while passively blowing these balloons, enchanted by their beauty, we have, perhaps, been "castle building," or thinking of all sorts of things not in the least connected with our bubble!

In this paper we are to discard the notion that a soap bubble is a mere fleeting plaything of childhood; we are to look on it as something which can furnish us, if we study it, with the means of acquiring some important science lessons.

Sir Isaac Newton said of the soap bubble, that he who could blow a permanent one would confer a great benefit on mankind. The truth of this remark will be more apparent presently.

We cannot get a permanent soap bubble, but by care we can get one to last some considerable time. The permanency will depend in a great measure on the "consistency" of the mixture from which the bubble is blown, and the care we take to protect it from draughts.

One general plan of making this mixture was to

scrape a little ordinary soap; rub it up in a little warm water, till it came into a foam. It is, however, a matter of importance that we should get a good mixture for the purpose, as many successors of Sir Isaac Newton have found. One of these recipes we find given in an old scientific treatise is as follows:—"Put into a common white bottle a quarter of a drachm of soap and two ounces of distilled water. Gradually heat the mixture till the soap dissolves." Professor Dewar, in his juvenile lectures at the Royal Institution during the Christmastide of 1878, gave the following as a good mixture: Soap, $1\frac{1}{2}$ oz.; water, 20 oz.; glycerine, 15 oz. This is very similar to Plateau's solution, which is made of castile soap, $1\frac{1}{2}$ oz.; water, 1 pint; glycerine, $\frac{3}{4}$ pint.

We mention Plateau's solution because the results due to the researches of this philosopher are beautiful to contemplate, and all the more so from the fact, that being blind, he has himself only the pleasure of seeing them with the eyes of the mind, and many of the experiments which we shall be able to introduce are from the results of his researches.

Either of the two latter solutions will furnish us with a good material for blowing bubbles as objects of study, and we have been thus particular in quoting these various methods, because the film is all important though it be but for a bubble.

Having got the proper solution, we can use in the blowing either an ordinary tobacco pipe, or a cleanly-cut glass tube; then with a little practice we shall be able to get bubbles a considerable size, nine or ten inches in diameter, or even bigger if necessary. To blow very large bubbles with the mouth is difficult; we may therefore attach our tube to a pair of ordinary bellows, or, better still, to the double-bellows used in blowpipe experiments.

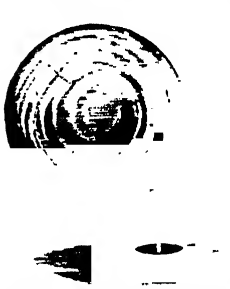


Fig. 1.—Support-stand for the Soap Bubble.

A good support for our bubble can be made of a ring of wire, bent as shown in Fig. 1, having its stem fastened into a block of lead.

After making the ring let it be heated and dipped into a block of paraffine, or let it be smeared over with this substance; it prevents the wire from cutting into the film. The bubble, supported on the stand, may be covered with a glass shade, and kept for a considerable time. In blowing bubbles, we repeat that they must be kept as free as possible from draughts of air. Thus protected we may preserve the beautiful bubble as an object for study.

We will now inquire into some of the lessons our bubble can teach us. This we will do by first considering its substance, next its form, and lastly its properties.

First, then, let us examine its substance. The bubble itself consists of a portion of air enclosed by a film, which consists of soap and water. We know that a film of water cannot be produced sufficiently durable for our purpose, therefore the substance of the film depends equally on the soap. So that the bubble is a combination of the three well-known forms of matter, the *solid*, *liquid*, and *gaseous*.

In this order we will consider them. The soap is formed from a fat, and a "metallic oxide," but as the chemistry of soap-making will at a future date be considered, we may dismiss it with this brief mention. The best bubbles for experiments are made with the purest soap and the purest water. To these may be added pure glycerine.

Within this film we enclose a quantity of air. When small bubbles are blown from the mouth the air with which we fill them is warmer than the surrounding air, and consequently lighter, therefore they rise, and it is this added to their beauty that gives them such a charm as toys in childhood. When filled from bellows, they have not this property of lightness, but are heavier and have a tendency to fall rather than to rise, because, added to the weight of the air enclosed, there is the weight of the film. Even with our toy-bubble, with its tendency to rise or fall, we get to know something of the fluidity and pressure of the air. The very fact that a bubble of warm air floats in colder air shows the liquid property of buoyancy, for as soon as the bubble cools so that its temperature is the same as that of the surrounding air, then it falls. This air-pressure, which is the cause of any substance floating in it, and which we measure by the barometer, is equal to 15 lbs. per square inch. This we call one atmosphere, a pressure of 30 lbs. two atmospheres, and so on. This can be substantially illustrated by a rod of lead having a sectional area of one square inch, and 36 inches long, for the weight of such a rod represents the weight of one atmosphere, or 15 lbs. Different airs or gases have different weights. This may be prettily demonstrated by taking a vessel of any description, *e.g.*, the glass shade with which we proposed to save our bubble from harm. Put into it a few pieces of

chalk. Pour over them a little vinegar. A bubbling will be set up, and a gas set free, which we call carbonic acid gas. Its presence can be tested by putting in a lighted match, which this gas at once extinguishes. Fill a bubble with ordinary air, and let it fall into the vessel containing the carbonic acid. It will remain supported—apparently on nothing, for this air is invisible—as long as any of the gas is left (Fig 2).

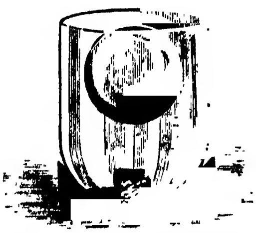


Fig. 2.—Air Bubble Floating in Carbonic Acid.

If you have any means at hand to fill a bubble with hydrogen, it will, as soon as released, bound upwards at a great rate, for this air is much lighter, and the lightest known. The former gas is one and a half times as heavy, and the latter fourteen and a half times lighter than common air (Vol. I., p. 284).

We have next to inquire into the form of the bubble. It is more or less that of a sphere, though, owing to the ease with which its form is changed and interfered with, it is never that of a perfect sphere. As it is being blown, or when it is suspended, its shape is more like that of a lemon; as it rests on the surface, or in the wire frame, it is more like that of an orange. Its form, therefore, is spheroidal. Why does it take this shape? We find all bubbles and drops assume the globular form, and such is the tendency of our soap bubble. Rain-drops and dew-drops are spherical. In the manufacture of shot, the liquid metal, as it falls from the various-sized sieves at the top of the tower, takes this same form. If a little water be dropped upon a greasy surface it takes the globular form; quicksilver will do the same when dropped upon any surface that it does not wet. Why is this globular form so persistently taken up by all liquids? If we dip our fingers into water we find, on withdrawing them, that drops remain suspended, of this form. The drop is composed of tiny particles, of which each has an attractive force for the other, and this being the same for every particle, the forces are equal, and all tend to draw the particles to a central point, and as they balance, all particles are equally distributed about the centre, giving the drop its globular form. In the case of a bubble the force is reversed, for the air is driven into the midst of the film, so that it is spread out on all sides with an equal force, and every part is pushed out with an equal force from the centre, and under this force the bubble will keep increasing in size, till the tenacity of the soap solution is overcome, when it will burst.

The force that gives form to the drop is that universal one which we call "gravitation," and this not only draws masses towards each other giving them form, but from this force they derive their *weight*.

The form of our bubble is due to the cohesion in the soap solution, and the combined elasticity of air and the solution. Cohesion, or the force with which one particle sticks to another, is perhaps more easily understood in the solid than in the liquid. In the liquid it does not exist in a large degree, the great difference between the liquid and the solid being perhaps determined by the amount of cohesion between the particles, for the particles of a liquid readily move about among each other—with such a very small amount of hindrance—while in the solid the particles are fixed, and so cannot be displaced, except by the use of force.

Directly we thicken a liquid, as we do water by the addition of soap, then we increase its cohesion.

This is noticeable in all thick liquids; oil, treacle, tar, are instances in which this property is apparent in different degrees. Such liquids form a sort of medium between the solid and liquid, and are said to exist in a "viscous" state.

When a quantity of the soap solution is taken at the end of the tube, previous to blowing, the mass is compact; into this the air is blown. It gradually spreads out, becoming globular in form, and thinner in film. The very thinness to which it can be reduced and still keep its completeness is a good example of its cohesion. Its elasticity is exhibited in bursting, by the rapidity with which the film flies back into its original bulk.

The elasticity of the confined air and film together form a very delicate thermoscope, for it readily detects any alteration in temperature. The following experiment proves this:—Take a bubble supported on one of the stands, as in Fig. 1. Bring any warm object near it; it at once increases in size. Frequently the hands held near it are sufficient to increase its size considerably. To show the delicacy with which the bubble detects a lowering of the temperature we need only put under a shade one of fair size, and with it a little ether, either in a spoon or small saucer. The air confined in the shade will have its temperature lowered so much by the evaporation of the ether as to diminish the bubble considerably in bulk. The force which the outer film exerts in the enclosed air is greater than we imagine, and is very much greater than that which it could exert in any other way.

This outside pressure may be roughly illustrated by taking one of the ordinary coloured thin balloons so largely sold for toys. Let one of these be allowed to collapse, by cutting the string at the mouth. Then by means of a syringe re-fill the balloon with water, and let it be tied up. Now let the water balloon be carefully pricked with a fine needle. This must be very carefully done, or the balloon will burst altogether. A little jet of water will spurt upwards (Fig. 3), forming a pretty miniature fountain. This result is entirely due to the pressure exerted upon the enclosed liquid by the elastic force of the membrane forming the balloon. If a fine glass tube be inserted into the balloon the jet will rise still higher.

Fig. 3.—Experiment with Water Balloon.

The test of the pressure exerted by the film of soap is a little more elaborate, but none the less telling.

Another example of the attraction that one body has for another of the same kind may be shown by putting two or three bubbles on a plate. They are attracted towards each other, this force increasing the nearer they approach, and at last they will frequently collapse, forming one large bubble.

If a bubble be pierced with a wire, the air escapes, and the bubble collapses, but if a thread of unspun silk be woven in, as it were, with the film, and even puncture it, the thread floats in it without breaking it. With our soap solution we can also obtain very beautiful geometrical forms, as well as bubbles. If we make for ourselves some wire frames of aluminium, as shown in Fig. 4, we can obtain some interesting figures. By carefully using (*c*) one of them with our bubble, we can draw it into a cylinder form. The dark lines represent the frames, and the dotted those of the film.

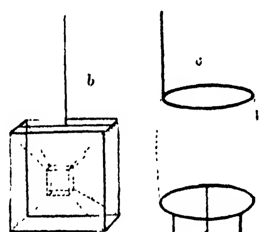


Fig. 4.—Soap Solution Experiments with Wire Frames.

With the frames *a* and *b*, in Fig. 4, we shall have films taken up by them on dipping them into the soap solution; and by pricking some of the outer surfaces other forms are frequently produced.

In addition to the cohesive force at work in the formation of a bubble, we must not forget another very important force, and that is the attraction which takes place between a solid and a liquid when the former is wetted by the latter.

This can be readily illustrated by taking a fine glass tube, and dipping it into a small portion of quicksilver, as in Fig. 5, *a*. The liquid does not rise in the tube at all, but is seen to stand below the level of that in the outer vessel. The liquid is repelled by the glass, and therefore does not *wet* it. Now immerse the glass tube in a little water, and it rises quickly in the tube, and stands at a much higher level than that in the vessel outside the tube, as in Fig. 5, *b*.

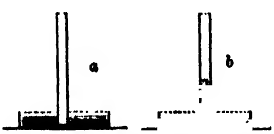


Fig. 5.—Attraction Experiment with Glass Tube and (*a*) Mercury, and with Glass Tube and (*b*) Water.

The finer the bore of the tube employed, the higher will be the point to which the liquid will rise. If a series of tubes of different sizes be taken in this experiment, the liquid will rise to a different height in each, and highest in that of the finest bore. A still better way to illustrate this force is to take a pair of glass plates of three or four inches square; put them face to face, let one edge of each piece be held tightly, with an elastic strap, for example, while the other edges are kept slightly apart by a wedge of wood, as in Fig. 6. Now let these plates be placed in a little coloured water, the liquid will rise above the level of that in the vessel, and will stand highest at the edges where they touch, so that a beautiful curve will be formed.

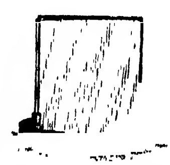


Fig. 6.—Attraction Experiment with two Glass Plates.

The illustrious Faraday had a pretty experiment, which he showed in his first Christmas course of lectures to a juvenile audience at the Royal Institution, which well illustrated this force. He took a bar of salt, neatly cut with a square base, and set it upright in a dish (Fig. 7), into which he poured coloured liquid. The liquid rapidly rose in the pillar of salt, which after a time fell over in consequence of the being dissolved away. This force we call *lary attraction*, and it is at work not only in the

Fig. 7.—Faraday's Experiment illustrating Capillary Attraction.

supply of moisture to the growing plant, but in the wicks of our lamps and candles. We have known this force to demonstrate for itself when not required to do so. A friend of the writer's, after washing his hands, hastily threw down the towel on to the wash-table. A corner of it found its way into the water, which gradually spread itself upwards from the corner, wetting the whole towel, and thus transferred, quietly but surely, every drop of water from the basin to the floor. By combining fibres of silk with the wire frames we can, by means of the capillary attraction—which induces the liquid to run even more readily along the silk than along the metal—get with the soap solution a still larger variety of very interesting and beautiful forms, which we can vary as our fancy may dictate.

We must now deal with its properties. These are principally dependent on its extreme thinness. The beautiful variety of colour is owing to the varying thickness of the film; and here again we must refer to experiments of Sir Isaac Newton. When the bubble is first blown it is colourless, but as it spreads itself out its walls become thinner and thinner; various tints appear, till in a black spot it reaches its extreme thinness; then, if the blowing be continued, it bursts. All thin films reflect colours, as may be readily seen by pouring oil or turpentine into water, and even by enclosing a film of air between two dry plates of glass.

The colours in a bubble will be of a more brilliant variety when more glycerine is added to the solution; in fact they then become perfectly gorgeous, and even the black spot does not appear.

Sir Isaac Newton succeeded in measuring the thickness of the film by the colour. He took a plano-convex lens (A, B), as in Fig. 8, on the curved surface of which he laid a plate of glass (C, D); thus he obtained a film of air of gradually increasing depth. On looking at this film by a "monochromatic" light, either directly through it or by reflection, he found that a number of bright rings surrounded the place of contact between the two glasses, and between each of these bright rings was a dark one, and that these rings were closer together as they were farther from the point where the two glasses touched. When red light was employed, these rings had certain diameters, when blue light was employed the rings were less in diameter, and so on with the other tints. The effect is very pretty when the glasses are passed through the spectrum from the red to the blue, for then the rings contract; while, when the passage is reversed, the rings expand. When white light passes through the glasses iris-coloured rings appear. Thus we get what is known as Newton's rings (Fig. 9).

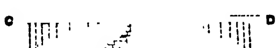


Fig. 8.—Newton's Plan for Measuring the Thickness of a Film of Air.

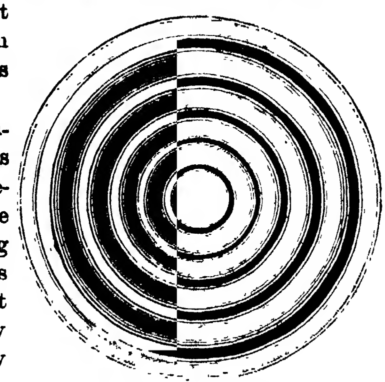


Fig. 9.—Newton's Rings.

Newton compared the tints of the bubble-film in the same way, detecting the thicknesses of each part of the film by the colour. By this means he arrived at the fact that the colourless, or black spot, was not more than a millionth part of an inch in thickness. How small must be the depth of water at this spot, and how much smaller still the particle of soap which it holds in solution!

From Newton's "Optics" we select a few of the thicknesses of the air-film to produce the accompanying colours, these being produced by reflected light.

	Of an inch.
Sky-blue	$\frac{2}{1000000}$
Orange red	$\frac{8}{1000000}$
Geranium red	$\frac{2}{1000000}$
Violet	$\frac{11}{1000000}$
Sea-green	$\frac{15}{1000000}$
Purple	$\frac{21}{1000000}$
Pale yellow	$\frac{27}{1000000}$
Lemon yellow	$\frac{16}{1000000}$
Greenish blue	$\frac{71}{1000000}$
Pale rose red	$\frac{65}{1000000}$

The colours of the bubble change as its thicknesses vary by evaporation. As it is suspended in the air, watch it, and you will find that it does so.

Any film, we have said, will produce these same colours, and these colours will change with the alteration in the thickness of the film. Take a quantity of spirits of turpentine; pour some of it on a pond or river; a variety of colours start from the central spot. Let it be followed by a second quantity; the series of colour is at once changed, and every ring, as it recedes from the centre, takes up a different colour. A film of air between two plates of glass will change its colour according to the tightness with which the plates are squeezed

together. A piece of talc, which looks nearly transparent and colourless when of the thickness of ordinary window-glass, if split up into very thin plates, assumes all the colours of other films, varying with the thickness.

We have it on record that Boyle, the eminent natural philosopher, some sixteen or eighteen years before Newton, obtained these films with pitch, rosin, turpentine, solution of gum, glutinous liquors, spirits of wine, oil of turpentine, glair of snails, &c.

Now why has the bubble colour at all? We know that light gives colour to all natural objects, and the bubble is coloured in the same way. All light is either absorbed or reflected, and our bubble follows the same plan with the light that is diffused on all sides of it. We have the images of various surrounding objects reflected on its surface, as well as the variety of colour.

Let us trace, if we can, how this curved, beautiful bubble disposes of the light. Suppose we have one suspended in sunlight. The various beams of light strike on its outer surface; part of it is at once reflected, but a large portion goes through the film and travels on till it strikes the inner surface of the opposite side. Here a second reflection takes place, and a large portion of the light that struck its first surface passes through it altogether. As the varying thicknesses of the film alter the rate at which light travels through it, so it will alter the rate at which one set of waves will follow upon another.

The white light is composed of seven colours, with which we are familiar in the rainbow, and it is the manner in which these various colours are disposed that determines what colour the object shall present to the eye. The absorbed colours do not effect this, but the reflected colours do. So it is with our bubble; the portion of the film that absorbs all the colours and reflects the blue appears blue, and so on with the others. And as we have seen that every condition of absorption and reflection is altered as the thickness of the film is altered, so it is that our bubble takes up the ever-varying series of bright and delicate tints.

Having thus briefly discussed the natural laws that determine the form and beauty of a soap-bubble, we have a key to a much wider field, which is constantly presenting itself to us in the ordinary routine of daily life. It is the familiarity with common things that robs them of much of that thought that we might otherwise bestow upon them.

A BUTTERFLY.

By Arthur G. Butler, F.L.S., F.Z.S.,

Assistant Keeper of the Zoological Department, British Museum.

THE life of a butterfly is a continued series of changes, from the time when it leaves the egg until it arrives at its perfect condition, not merely in the gradual acquisition of new organs, but in the shedding of the larval, or caterpillar skins, at intervals before it attains its full growth. In most moths and butterflies these changes of skin are said to occur about five times, but in some species this number is known to double itself.

The eggs of butterflies vary considerably both in form and sculpture, being in some species more or less pear-shaped, in others spherical, cylindrical, or barrel-shaped, with concentric, longitudinal, or netted lines and ridges; the apex being frequently more or less depressed. When first deposited upon the food-plant they are usually of a pale yellow colour, which gradually deepens as the young caterpillar is developed within, so that just before hatching they are of a dark purplish or blackish tint.

Almost immediately after exclusion the caterpillar attacks its food, generally beginning upon the empty shell from which it has emerged. Its size at this time is very small, the common silkworm being then, according to Count Dandolo, scarcely a line in length, and weighing not more than the hundredth of a grain; whereas, at the end of thirty days, when it has attained its full size, its average weight is about ninety-five grains, and its length occasionally forty lines, so that its weight in the course of this time has increased nine thousand five hundred-fold.

The body of a caterpillar is composed of thirteen distinct segments or rings, the first of which constitutes the head. It is strong and horny, furnished with a complete mouth and powerful jaws. The antennæ are extremely minute, and the eyes are represented by a small group of ocelli placed on each side; the labium is furnished with a short

tubular protuberance, into which the silk glands open: these consist of two elongated, flexuous, thick-walled sacs, situated at the sides.

The second, third, and fourth segments * represent the thorax of the future butterfly, while the others form the abdomen. The thoracic segments are provided with short curved legs, the rudiments of the future limbs; and the seventh to the tenth with pairs of false or abdominal legs, consisting of processes from the exterior covering of the insect, furnished externally with developments of the cuticle, in the form of hardened spines or hooks. The form of these feet usually resembles an inverted cone, with its apex truncated to form a flat sole, upon which the caterpillar walks. This sole can, when necessary, be rendered concave in the middle, and the minute hooks round its margin, when the foot is pressed upon a convex surface in walking, are necessarily directed inwards, and thus secure a firm attachment (Fig. 1). A still stronger hold is attained by a pair of somewhat similar feet, or claspers, upon the anal segment.

The muscles of the larva are extremely uniform in their size and distribution in each segment, the principal differences between them existing in the first four segments, composing the head and thorax of the perfect insect. In the head, for instance, there is necessarily a greater number of muscles than in the other segments, owing to the number of organs requiring them; but the form and position of these muscles differ from those of the other segments. The muscles of the mandibles are large, and occupy the greater part of the side and hinder region of the head; the extensor muscles being attached to the side and hinder surface of the cavity, like the extensor muscles of the legs in the chest segments, and the flexor more internally to parts corresponding with the *laminæ squamosæ* in the head of the imago, or perfect insect (Newport).

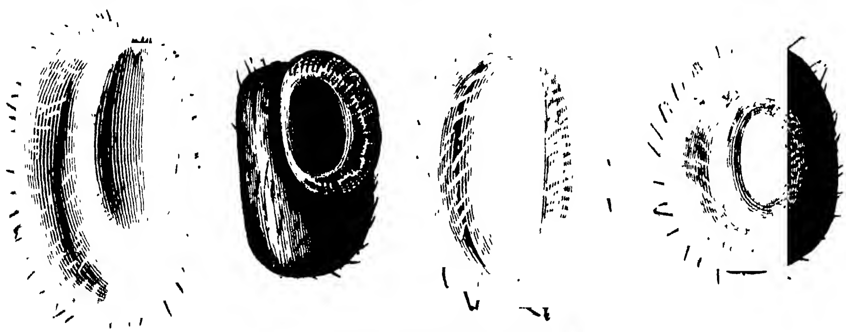


Fig. 1.—Membranous Feet of Caterpillars.

* Strictly speaking, also part of the fifth segment.

The muscles of the three "thoracic" or chest segments are more numerous and complex than those of the abdomen, or belly, because the true organs of locomotion belong to these segments, as well as the rudiments of the muscles for the future wings. Those muscles which form distinct layers, or act in concert with each other, are inserted into slightly raised ridges of the tegument. Three of these ridges are situated between two abdominal segments, from the middle or largest of which the longitudinal muscles originate, while the oblique muscles start from the two others.

The nervous system is represented by two longitudinal cords extending along the centre line of the under surface, and possessing in the more advanced stages of growth a series of ganglia, or knots, corresponding with the segments in which they are placed, the pair situated in the head representing the brain of higher animals.

The development of the brain and nervous cord alters remarkably in character during the metamorphoses. These changes have been studied most carefully by Newport and Herold in the case of *Pieris* and *Vanessa*. In the imago, or perfect condition, the ventral (or under) cord consists of seven ganglia, while in the larva there are eleven. This decrease in their number is due to the coalescence, during the pupal condition, of the first, second, third, and fourth ganglia of the larva, exclusive of those which are situated in the front part of the head; these form the two thoracic ganglia, which distribute nerves to the legs and the muscles of the wings. The fifth and sixth ganglia of the larva have, in the meantime, either entirely disappeared or been united with the others (Figs. 2, 3, and 4).

The alimentary canal commences with a somewhat elongated "œsophagus" (gullet) opening into the stomach; the "ilium" (small intestine) is long, and frequently forms several convolutions; the "colon" (or large intestine) is often dilated into a "cæcum" (pouch) in front. The salivary glands consist of two large and simple tubes extending into the abdomen. The breathing system is well developed: the stigmata are wanting on the second

and third thoracic (chest) and the last abdominal (belly) segments.

Before changing to the chrysalis, pupa, or second stage, the larvæ of butterflies become uneasy, leave off

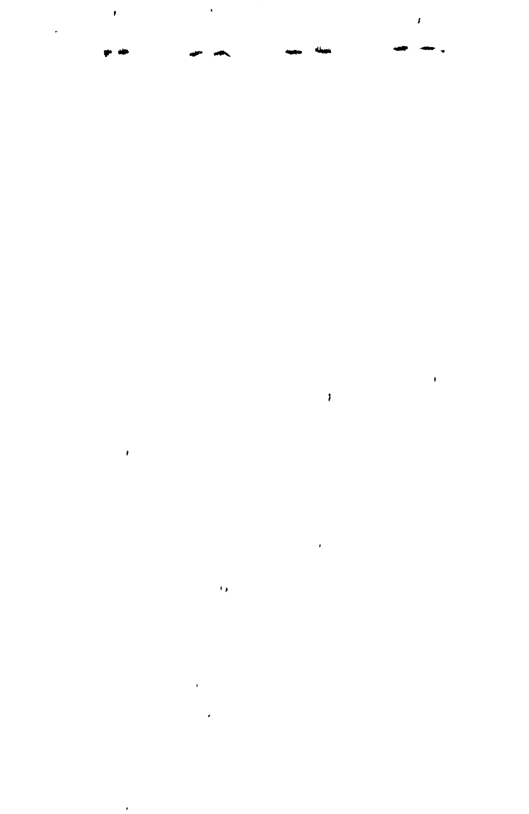


Fig. 2.—Metamorphoses of the Nervous System of *Vanessa Urticæ*.

(1) Nervous System of full-grown Larva; (2) Half-an-hour before changing; (3) Immediately after changing into a Pupa or Chrysalis; (4) One hour after changing. (*After Newport.*)

feeding, and wander about seeking a place in which to secure themselves in anticipation of the event. The disinclination for food is often apparent a day or two before the metamorphosis takes place; but some species continue to eat up to within a few hours of pupation. This crowning event in the life of the caterpillar may be best illustrated by quoting Mr. Charles V. Riley's admirable description* of the pupation of the North American Butterfly, *Danais plexippus* (Linn.)

"As soon as the larva is full grown it spins a little tuft of silk to the under side of whatever object it may be resting upon, and after entangling the hooks of its hind legs in this silk it lets go the hold of its other legs and hangs down, with the head and anterior joints of the body curved. In this position it hangs for about twenty-four hours, during which the fluids of the body naturally gravitate towards the upturned joints, until the latter become so swollen that at last, by a little effort on the part of the larva, the skin bursts along the back behind the head. Through the rent thus made the anterior portion of the pupa is protruded, and by constant stretching and contracting the larval skin is slipped and crowded backwards, until there is but a small shrivelled mass gathered around the tail. Now comes the critical period—the culminating point. The soft and supple chrysalis, yet showing the elongate larval form with distinct traces of its pro-legs, hangs heavily from the shrunken skin. From this skin it is to be extricated and firmly attached to the silk outside. It has neither legs nor arms, and we should suppose that it would inevitably fall while endeavouring to accomplish this object. But the task is performed with the utmost surety, though appearing so perilous to us. The supple and contractile joints of the abdomen are made to subserve the purpose of legs, and by

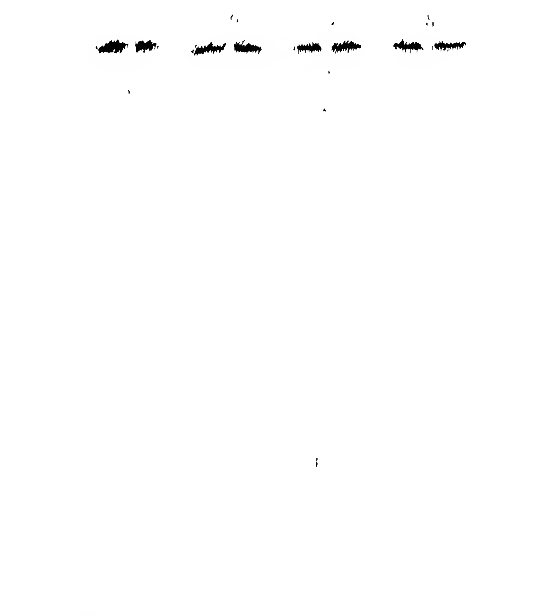


Fig. 3.—Metamorphoses of the Nervous System of *Vanessa Urticæ*

(5) Twelve hours after changing; (6) Eighteen hours after changing; (7) Twenty-four hours after changing; (8) Thirty-six hours after changing. (*After Newport.*)

suddenly grasping the shrunken larval skin between the folds of two of these joints, as with a pair of pincers, the chrysalis disengages the tip of its body and hangs for a moment suspended. Then with a

* "Third Annual Report of the Noxious, Beneficial, and other Insects of the State of Missouri," pp. 147-8. See also Butler in *Journal, Wellington Phil. Soc.*, 1878, pp. 267-8.

few earnest, vigorous, jerking movements it succeeds in sticking the horny point of its tail into the silk, and firmly fastening it by means of a rasp of minute claws with which that point is furnished.

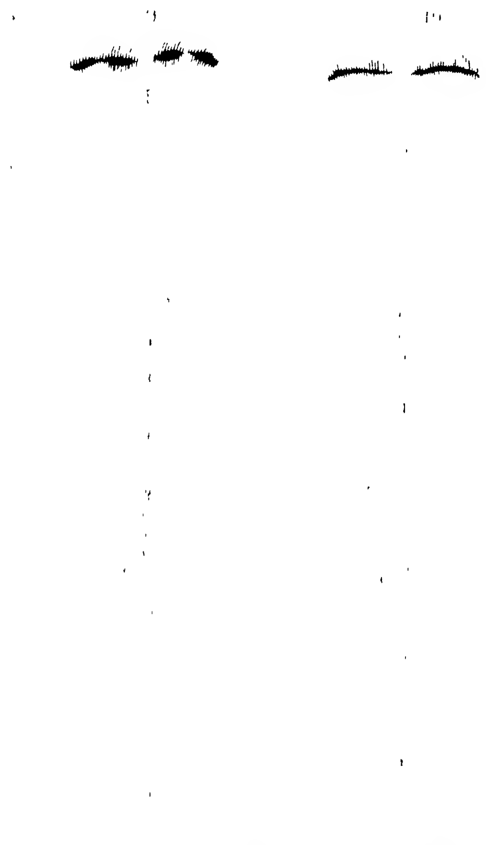


Fig. 4.—Metamorphoses of the Nervous System of *Vanessa Urticæ*. (9) Forty-eight hours after changing; (10) Fifty-eight hours after changing [more highly magnified than in Figs. 2 and 3]. (*After Newport.*)

Sometimes severe effort is needed before the point is properly fastened, and the chrysalis frequently has to climb by stretching the two joints above those by which it is suspended, and clinging hold of the shrivelled skin farther up. The moment the point is fastened the chrysalis commences, by a series of violent jerkings and whirlings, to dislodge the larval skin, after which it rests from its efforts and gradually contracts and hardens. The really active work lasts but a few minutes, and the insect rarely fails to go through with it successfully. The chrysalis is a beautiful object, and as it hangs pendent from some old fence-board or from the under side of an *Asclepias* leaf it reminds one of some large ear-drop; but though the jeweller could successfully imitate the form, he might well despair of ever producing the clear pale-green and the ivory-black and golden marks which so characterise it. This chrysalis state lasts but a short time, as is the case with all those which are known to suspend themselves nakedly by the tail. At the end of about the tenth day the dark colours of the future butterfly begin to show through the delicate and transparent skin, and suddenly this skin bursts open near the head, and the new-born butterfly gradually extricates itself, and, stretching forth its legs, and clambering on to some surrounding object, allows its moist, thickened, and contracted wings to hang listlessly from the body" (Figs. 6, 7).

We now come to the imago, or perfect state; and before proceeding farther it is advisable to ask and answer the oft-repeated question :—"How may a butterfly be distinguished from a moth?"

To answer this question satisfactorily one might search in vain through the text-books of science. The answers given are plausible enough, but are contradicted by the subsequent statements of the very authors who advance them. A careful study of the whole of the Lepidoptera, indigenous and foreign, will be sufficient to convince any candid student that the division into butterflies and moths is an arbitrary one, having no existence in Nature.

The fact that in the early days of science the Lepidoptera—that is, the moth and butterfly order of insects—were separated into two groups by the form of the antennæ, or "horns"—those with clubbed horns being called Rhopalocera, and those with other kinds of horns Heterocera—has been sufficient reason to induce over-conservative naturalists to squander valuable time in seeking for other differences wherewith to strengthen the widespread belief in this unnatural division, but up to the present time no character without an exception has been brought to light.

As the fallacy respecting the antennal differences is the most widespread and the most boldly asserted, even by the best modern teachers, I shall not here tax the patience of my readers by disproving the correctness of all, but shall confine myself strictly to this one point.

In order to do this I will first quote a few passages from one of the most frequently consulted of modern works, showing their contradictory character; and then I will proceed to adduce fresh evidence, obtained by a personal study of the order. Dr. Packard, in his well-known "Guide to the Study of Insects," makes the following orthodox statements :—"Butterflies are easily distinguished from

the other groups by their knobbed antennæ. In the Sphinges and their allies the feelers are thickened in the middle; in the moths they are filiform, and often pectinated like feathers."*

"The butterflies, or diurnal Lepidoptera, are at once distinguished from the moths by their knobbed antennæ, though they are sometimes nearly filiform."†

"The Hesperians, or Skippers, are a large group of small dun-coloured butterflies, whose antennæ have the knob curved like a hook, or ending in a little point bent to one side, reminding us of the antennæ of the Sphinges."‡

"*Zygænidæ* (Latreille).—This interesting group connects the diurnal with the nocturnal Lepidoptera. Some of the forms (Castnia) remind us strikingly of the butterflies. The group may be recognised by the rather large free head and the simple antennæ, which are slightly swollen in the middle, or partially clavate, as in Zygæna."§

So far Dr. Packard; but it will be easy to show that a closer investigation will entirely set aside the antennal character. However, not to multiply instances unnecessarily, we will simply ask the reader to compare with us the following genera, and judge for himself (Fig. 5).

The most satisfactory instance of a decidedly knobbed antenna among the moths occurs in the family *Sphingidæ* and has received the name of *Rhopalopsyche* (Fig. 5, B). This genus, in the form of its feelers, so perfectly agrees with the butterflies of the genus *Pamphila* (Fig. 5, A) that it alone would be sufficient to set aside the distinction between the Rhopalocera and Heterocera; but in the next place, if we take the genera *Zethera* (Fig. 5, E) and *Rothia* (Fig. 5, F), the butterfly has no perceptible club, whilst the moth shows a trace of one. If we take *Plastingia* (Fig. 5, C) and *Cocytia* (Fig. 5, D) we again find the moth more Rhopalocerous than the butterfly; finally, in the Heterocerous genus *Synemon* all the species have distinctly clubbed antennæ, in which the clavus is more abruptly formed even than in *Cyclopides* or in most of the species of *Pamphila*.

The only instance known of a butterfly exhibiting a tendency to pectination (like the teeth of a comb) in the horns occurs in the genus *Barbicornis* (Fig. 5, G) of the family *Erycinidæ*. The species of this group have thickened moniliform (bead-like) antennæ, from the joints of which, by the help of a good lens, one can distinctly see little bristles projecting.

As it must be admitted that the separation of the order into butterflies and moths is a convenience to collectors, there is not the slightest reason why this arbitrary division should not be maintained in the cabinet; but in order to do this satisfactorily the collector must study the characters of the families until his eye becomes accustomed to their peculiarities, or he will be certain to make mistakes. The butterflies constitute the first five families of the Lepidoptera, and as no two families can be identical in structure and habits, it will only be necessary for the student to understand the peculiarities of these five large groups to enable him to discriminate between butterflies and moths.

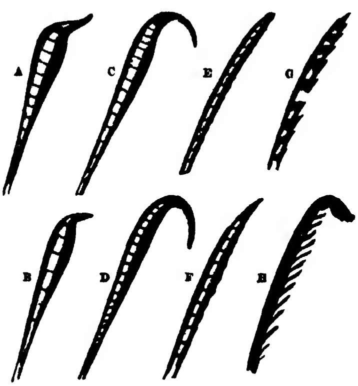


Fig. 5.—Antennæ of Butterflies (A, C, E, G), and of Moths (B, D, F, H).

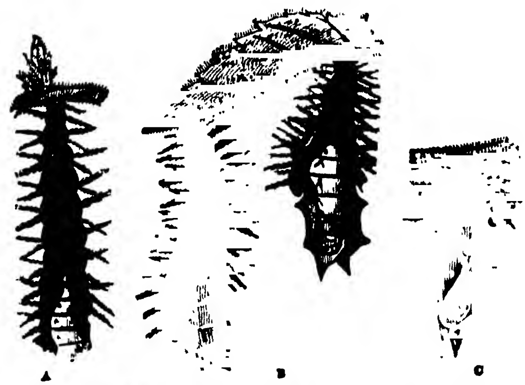


Fig. 6.—Larvæ and Pupæ (Chrysalides) of *Vanessa Urticæ*. Three Stages of Chrysalis development:—(A, B) The Larva-skin ...ng; (C) Perfect ...

The following classification of the so-called Rhopalocera is that proposed by Mr. H. W. Bates,|| and now almost universally adopted by lepidopterists.

Family 1. NYMPHALIDÆ.—Front legs imperfect in

* Page 241. † Page 244.
‡ Page 269. § Page 279.

|| In his excellent paper published in the *Journal of Entomology* for 1864.

both sexes, in the female wanting the tarsal claws; in the male the fore tarsi quite rudimentary, consisting of one or two spineless joints. Pupa suspended freely by the tail.

a. Lower disco-cellular nervule of the hind wing perfect.

Sub-family 1. *Danainæ.*—Larvæ smooth, with fleshy processes. Fore-wing sub-median nervure of the imago double at its origin. (This sub-family includes the greater part of the *Heliconidæ* of authors.)

Sub-family 2. *Satyrinæ.*—Larvæ with bifid tails, spineless. Palpi of the imago generally compressed and fringed with long hair-scales.

Sub-family 3. *Brassolinæ.*—Larvæ generally with bifid tails, spineless. Hind wing of the imago furnished with a pre-discoidal cell.

Sub-family 4. *Acræinæ.*—Larvæ studded with branched spines. Palpi of the imago thick and scantily clothed with hair.

Sub-family 5. *Heliconinæ.*—Larvæ studded with branched spines. Palpi of the imago clothed with fine scales, and hairy in front.

b. Lower disco-cellular nervule, at least of the hind wing, more or less atrophied.

Sub-family 6. *Nymphalinæ.*

Family 2. ERYCINIDÆ.—Six perfect legs in female; four in male; the anterior tarsi consisting only of one or two joints and spineless.

Fig. 7.—Chrysalides of the Pieris brassicæ.

Sub-family 1. *Libytheinæ.* — Pupa suspended freely by the tail.

Sub-family 2. *Stalachtinæ.* —Pupa secured rigidly by the tail in an inclined position without girdle.

Sub-family 3. *Erycininæ.* —Pupa recumbent on a leaf or other object, and secured by the tail and a girdle across the middle.

Family 3. LYCÆNIDÆ.—Six perfect legs in female; four in male; the anterior tarsi wanting one or both of the tarsal claws, but densely spined beneath. Pupa secured by the tail and a girdle across the middle.

Family 4. PAPILIONIDÆ. —Six perfect legs in both sexes. Pupa secured by the tail and a girdle across the middle. (The true *Papiliones* have a leaf-like appendage to the fore tibiæ—a character which approximates the family to the *Hesperidæ* and moths.)

Sub-family 1. *Pierinæ.*—Abdominal margin of the hind wing not curved inwards.

Sub-family 2. *Papilioninæ.*—Abdominal margin of the hind wing curving inwards.

Family 5. HESPERIDÆ.—Six perfect legs in both sexes; hind tibiæ, with few exceptions, having two pairs of spurs. Pupa secured by many threads, or enclosed in a slight cocoon.

In order thoroughly to comprehend the above classification, it is of course necessary to study the external structure of a butterfly, particularly the veining of the wings, which is used more than any other character in the definition of sub-families and genera.

The body of a butterfly is divided into three well-marked regions—the head, thorax, and abdomen. The head is comparatively small, and the mouth parts greatly specialised so as to serve exclusively for suctorial purposes. The mandibles, prominent in most orders of insects, are here reduced to the merest rudiments, and are hidden under the hairs which clothe the front of the head. Between them there is a rudimentary labrum, or upper lip, and below the latter the proboscis, or sucking-tube, formed of the maxillæ. Each maxilla is composed of an immense number of short, transverse, muscular rings, convex on the outer surface, but concave on the inner; and the tube is produced by the approximation of the two organs. When not in use they are coiled up in the form of a watch-spring between the labial palpi. In some species the extremity of each maxilla is furnished along its anterior (front) and lateral (side) margin with numerous little papillæ, or prominences. In *Vanessa atalanta* they are little, elongated, bell-shaped bodies. These papillæ are supposed by some authors to be organs of taste.

The labial palpi in butterflies are usually of moderate size; in some genera, such as *Libythea*, being well developed; in the sub-family *Papilioninæ*, on the other hand, they are quite small, and do not extend to the front of the head. They consist generally of three joints, of which the terminal one is most frequently small and pointed; very often they are re-curved in front of the head.

If we remove the scales from the head of a butterfly, we shall see that it consists of three principal parts—the clypeus, or front of the head; the epicranium, lying behind the insertion of the antennæ, and bearing the ocelli and eyes; and the

occiput, or basal part lying behind the ocelli. The clypeus is larger in the Lepidoptera than in any other order of insects. The eyes are very large and compound, having numerous facets, each facet being the proper cornea of a distinct eye and perfectly transparent; it is convex both on its external and internal surface, like a lens. Immediately behind each facet is a layer of dark pigment, which covers the whole of the inner surface, excepting in the centre, where there is a minute aperture to admit the rays of light. Between this pigment (which represents the iris) and the end of the cornea is a space filled with watery moisture, and behind the iris of each cornea is a little conical transparent body, with its apex directed towards the axis of the eye. This body, which is filled with vitreous fluid, receives the rays of light admitted through the cornea, and directs them upon the retina, or termination of the nerve. In addition to these complicated eyes, many Lepidoptera also possess a pair of ocelli, but usually concealed amongst the thick hairs which clothe the head.

Of the form of the antennæ, or "horns," I have already spoken; their function has been a subject for dispute amongst naturalists, some asserting that they are organs of feeling, others of smelling, and others, again, of hearing. The experiments of Dr. Clemens with some of the larger North American *Bombyces* have proved that they assist in some way in guiding the flight of these insects; it is, however, quite possible that organs which vary so much in structure that they are constantly made use of in the discrimination of genera may have different functions, in accordance with the requirements of the various groups.

The thoracic segments form a compact ovate or roundish mass, generally well covered with rather long hair. The prothoracic ring is exceedingly small, the mesothorax, on the contrary, being enormously developed. The scutum is large, broadest behind the middle, and notched for the reception of the triangular scutellum, which is about one-fourth the size of the scutum. The metathorax is transverse and much compressed; it is little more than half the width of the mesothorax.

The abdomen is generally more or less oval in form, the number of segments varying from eight to nine. The genital armour of the males varies greatly in different genera, and is frequently used in characterising allied groups of species.

The wings are four in number, the anterior pair being most frequently of a triangular form, and the posterior pair pear-shaped, or sub-quadrate; but numerous and most extraordinary exceptions to this pattern occur. Their beautiful colouring is produced by multitudinous scales of various ornamental shapes, arranged in overlapping series, much after the pattern of Swiss tiles. These scales are inserted by means of a pedicle and bulb into little punctures in the membrane of the wing (p. 42). This membrane, which is either colourless or of a horn-like hue, is composed of chitine (a substance consisting, according to Mr. Children,

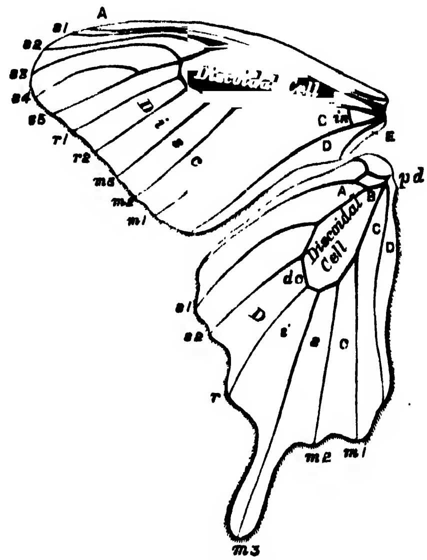


Fig. 8.—Skeleton of Butterfly's Wing.

(m 1—m 3) Median Branches; (r 1—r 2) Radials; (s 1—s 5) Subcostal Branches; (E) Internal Vein; (dc) Disco-cellular Veinlets; (in) Interno-median Veinlet.

of a combination of carbon, hydrogen, nitrogen, and oxygen). The scales are merely modifications of hair or bristles, as may be seen by studying the wing of *Callitæra* or other partially transparent genera under the microscope, when numerous bristles, or hairs, will be seen mixing with the scales, some of the latter, moreover, being imperfectly developed.

The surface of the wing is divided by five principal veins, with their branches, the vein nearest to the anterior margin being the costal vein (Fig. 8, A), which is usually simple, and joins the margin near its outer third. The second vein is called the subcostal (Fig. 8, B); it is always branched, the number of branches, or "nervules," seldom exceeding five, and reckoning forwards from the base of the wing towards the apex. In the posterior wings these nervules vary from two to three in number, the third being produced by a displacement of the radial or discoidal vein. The radials are simple, and usually start from the cross-veinlets, which, in most genera,

unite the sub-costal vein to the median, and are called the disco-cellulars; but in some instances the two radials of the anterior wings or the single radial of the posterior wing are abnormally situated, the upper radial being emitted as a branch of the sub-costal, and the lower radial as a fourth branch of the median. The median vein (Fig. 8, C) is placed almost in the central longitudinal line, and normally emits three nervules, which are reckoned in the order of their emission—that is, from the base towards the outer margin. The sub-median vein (Fig. 8, D) is usually simple, but in *Papilio* that of the anterior wings is united by a spur, or cross-vein (*in*) with the base of the median. The internal vein is a short nervure, seldom seen in the anterior wings, and placed next to the inner or abdominal margin. The discoidal cell is the area enclosed between the sub-costal and median veins, and usually shut in by the disco-cellular veinlets.

In describing the wing of a butterfly it is convenient to divide it into regions or interspaces, named after the veins which enclose them. The wing, then, will be divided as follows:—Costal region, sub-costal region, first to fourth sub-costal interspaces, first and second discoidal or radial interspaces, second and first median, interno-median, sub-median, internal. It may also be separated into imaginary areas, such as the basal, costal, sub-costal, discoidal, median, internal, discal, apical, external, and anal: all these terms being valuable in indicating the general position of the markings.

The legs of butterflies, as in other insects, are six in number; but in the higher and consequently more specialised families, the anterior pair is more or less aborted, particularly in the male sex, where it frequently looks like a little tuft of hair rather than a limb. Their thickness, length, hairiness, the length, number, or absence of their spines, and the presence or absence of tufts or fans of hair are all characters sought for, and studied with interest by the student.

Of the number of butterflies existing upon this globe it is impossible at present to speak definitely. Up to the present time somewhere about twelve thousand species are known. One thing is, however, certain, that the more we see of these beautiful insects the greater difficulty do we experience in discriminating between the crowds of closely-allied forms which constantly arrive from all parts of the world.

A PIECE OF WHINSTONE.

By Professor T. G. Bonney, M.A., F.R.S.

In many parts of England and Scotland the roads are mended with a hard, heavy stone, from a dark green to black in colour. Ask what it is, and if you are in northern districts you will be told it is whinstone. Whin is another name for furze, and probably the stone is thus named because this shrub commonly grows on the rough knolls and braes which often mark its outcrops. The term may sometimes be used a little vaguely, but properly it denotes the stone which by geologists is called basalt. It is one of the group of igneous rocks.

As we have begun with a heap of road-metal, we will describe basalt as a stone before we speak of it as a rock. The chemist tells us that it has approximately the following composition—silica, 50 per cent.; alumina, 19 per cent.; oxides of iron, 16 per cent.; lime, 9 per cent.; magnesia, 5 per cent.; soda, 3 per cent.; with a little potash, water, and very small amounts of phosphoric acid, and perhaps of other substances; and that its weight is not quite three times that of water.

The microscope will best show us its component minerals. By examining a very thin slice, prepared in the usual way, we find it consists almost wholly of a variety of felspar, augite, and iron peroxide, and generally more or less olivine (Fig. 1). On making use of polarised and analysed light, we find the felspar exhibit the curious parallel banding which denotes a species of the "triclinic" group; generally it is that called "labradorite." The augite often shows bright colours, and the olivine has a rather "frosted" look, and is frequently yet more brilliant in tint. The iron oxide appears in small black grains. But if a large collection of slides be examined they will be found to exhibit many variations. If the rock be rather decomposed, the felspar becomes dull and earthy and has been partly used to form the minerals called zeolites; green minerals akin to chlorite replace the augite, and serpentinous products the olivine. The iron becomes rusty, and a little calcspar makes its appearance. Sometimes the rock is coarsely, sometimes finely, crystalline.

In the former case, when the "grain" can be seen with the naked eye and the rock has a speckled look, it is called dolerite, and rather finer varieties are termed anamesite, basalt being reserved for the more compact. Occasionally, also, the mass of the rock is imperfectly crystallised, or is a glass crowded with minute crystals of the above-named minerals; then it is often called a glass-basalt.* Sometimes it occurs as a dark brown or purple-black glass, which is called tachylite. The last can be quickly distinguished from other black volcanic glasses by the ease with which it fuses before the blow-pipe.

Fig. 1.—Sketch of magnified Section of Basalt (*Dolerite*) from Dunfion, Arran.

(A) Augite; (B) Olivine; the black grain is magnetite or hematite; the remainder plagioclase felspar.

Other structures also occur. Sometimes basalt is porphyritic—that is, it shows in the mass of the rock distinct crystals of the component minerals: felspar, or augite, or olivine—one or more of them. Sometimes it is vesicular, or full of cavities. These, when the rock was solidifying, were occupied by steam or gas. Afterwards these occasionally become filled with zeolites, silica, or calcspar—and the rock, to use a homely simile, looks like almond toffee; from which appearance it is said to be amygdaloidal.† Instead of the felspar, the kindred minerals nepheline or leucite sometimes occur; then the rock is called either nepheline-basalt or leucite-basalt, but these have not yet been discovered in England.

Basalt, as we have said, is often rather decomposed. When this is slight, a greenish tinge is the result, but when considerable the colour and appearance of the rock are so changed that one could hardly believe it to have ever been a true basalt. Thus, owing to alteration of the iron constituent, the rock may be purple, or dull red, or rusty brown; sometimes it is a paler green, or a shade of grey, and occasionally a cream colour, almost white. Then it is often earthy, friable, and effervesces with acids. This rock is popularly called "white trap," and is the result of extreme decomposition, and the formation of carbonates, especially of lime and iron. The following is roughly its chemical composition:—Silica, 39 per cent.; alumina, 13 per cent.; lime, 4 per cent.; magnesia, 4 per cent.; soda, 1 per cent.; iron protoxide, 14 per cent.; iron peroxide, 4 per cent.; carbonic acid, 9 per cent.; water, 11 per cent.; with a little potash. White trap is common on the coast of Fife, and is found at Pouk Hill, near Walsall, among other localities.

We pass on now to speak of basalt as a rock mass. Often it has been poured out in lava streams from a volcanic vent. These are frequently of great size, for basalt seems capable of retaining its fluidity much longer than the lavas which contain more silica, as it solidifies at a lower temperature. One of the flows which issued from Skaptâ Jokul, in Iceland, in the year 1783, was fifty miles long and sometimes fifteen miles broad. The great tabular masses which form many of the islands of the Inner Hebrides, and the Giant's Causeway in Antrim, are fragments of huge lava flows; so are the masses which cap Titterstone Clee in Salop and the Rowley Hills in Staffordshire. Basalt is found also as an intrusive sheet, which sometimes runs so regularly between two beds of sedimentary rock as to be seemingly interstratified with them. Of this the Whin Sill in the North of England is an example, and other cases may be seen in the cliffs in the northern part of Skye. Sometimes basalt breaks in wall-like masses through other rocks. A most remarkable case of this may be seen at Strathaird, in Skye, where dyke succeeds dyke often at intervals of a few yards only; sometimes also basalt forms intrusive veins or small bosses.

Basalt contracts in cooling, and thus breaks, forming the divisional planes termed joints. These are often curiously regular, and give the rock the appearance of being composed of an immense number of columns. It must, however, be remembered that this columnar structure is not restricted to basalt, for it occurs in various more or less compact igneous rocks, but it is commoner in basalt than in the others. These columns are generally six-sided. They have evidently been caused by contraction in cooling, for in a flow they are usually vertical, in a dyke horizontal; where the outer surface of the mass has been curved, the columns lie at right angles to the surface. Some dykes indicate the cause very distinctly, for the columns do not meet in the middle, and thus have evidently started independently from the outside. Excellent examples of vertical columns

* The limits of the term "basalt" require settling. Also it must be borne in mind that the name is used both generically, as in this paper (including dolerite, &c.), and specifically for the compact, but not distinctly glassy varieties.

† Derived from the Greek word for an almond.

are seen at Fingal's Cave in Staffa (Fig. 2), and at the Giant's Causeway in Antrim. At the Spindle, near St. Andrews, they radiate from a centre. At the Clam-shell Cave (Staffa) they curve in a very remarkable way; and in some cases it is not easy to ascertain the precise cause of the curvature, for they bend about in a most anomalous manner; sometimes clustering in tufts, or diverging like the pinnules of a frond. Occasionally also the columns

Fig. 2.—Fingal's Cave, Staffa.

themselves are wavy, as though the mass had yielded a little after they were formed. Auvergne furnishes some remarkable cases of this.

Geologists for long were puzzled at finding the columns so often six-sided. This difficulty, however, has been explained by Mr. R. Mallet* as follows: The columns naturally adopt the form which requires in making the least amount of work. There are, however, only three equilateral shapes in which columns can be made so as to leave no interspaces when packed side by side. These are equilateral triangles, squares, and hexagons. Now as the mass cools from its exterior, the surface of temperature at which rupture takes place will gradually sink into it. Suppose, for simplicity the surface to be a plane, such as this paper and ready to break under the strain. Which of the three forms will be most easily produced This will depend upon two things: one, the resistance to breaking, which for a figure of given area, is proportional to the total length of the sides (because we may conceive the contiguous particles in the adjacent sides of two figures as clinging one to another): the other, the amount of the contractile force (acting towards the centre of the figure) which is at right angles to the side. In short, the form chosen will be that where there is least resistance to breaking and the greatest portion of the contractile force is expended in breaking. Of the three figures named above, a hexagon for the same area, has a smaller periphery than a square, and a square than an equilateral triangle. Thus a field of one acre would require the least amount of fencing when its plan was a hexagon. So there will be least resistance to rupture in a hexagonal column. Again, it can be proved that in a hexagon a greater part of the contractile force (which will be proportional to the area, and so the same in

* *Philosophical Magazine*, Series IV., Vol. I., p. 122.

each case) acts at right angles to the sides, and is thus effective in rupturing.* For these two reasons a hexagon is the most easily and an equilateral triangle the least easily produced, so that while the former are common, the latter are very rare.

The columns also generally break across after formation, as the cooling continues (Fig. 3), though sometimes very long shafts may be seen.

Fig. 3.—Basalt in Prismatic Columns.

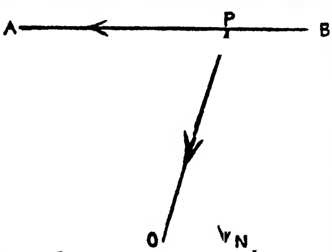
This fracture not seldom, instead of being plane, shows a cup-and-ball structure; the whole surface swelling up in a curve, or a part of a ball seeming to rise out of the flat hexagon, like a circular dome from the roof of a hexagonal tower. This structure also is the result of contraction, and shows that the column is losing heat pretty uniformly, not only from its surface, but also throughout its whole mass. When a solid is to be formed by contraction (for the reasons given above), there is none so easy as the sphere; since it for a given content has the least surface, and to this surface the whole of a central force acts at right angles. Thus there will be a great tendency for the cross cracks to take a curved shape, and for spherical or spheroidal cracks to form within the body of a column, even where, perhaps, the outside had become too firmly set to admit of rupture. So, when walking over a mass of columnar basalt, which, like the Giant's Causeway, has been partly washed away by the sea, we often observe the broken ends of the columns showing these projecting balls and their corresponding sockets (for sometimes the crack takes an upward, sometimes a downward direction). The weather, as it destroys the column, develops the spheroidal structure. Thus in some cases, as at the Käsegrotte, near Bertrich, in the Eifel, the columns look as if they were built up of Dutch cheeses; and in many places decomposing blocks of basalt will be found to exhibit a rudely spheroidal structure.

Basalt abounds on the west coast of Scotland, and among the Inner Hebrides; also in the Central Valley between the Grampians and the Southern Uplands, and in many other places. It is common in the north of England, especially towards the eastern coast, and occurs in Derbyshire—where it goes by the name of "toadstone"—Staffordshire, Shropshire, Leicestershire, in some parts of the south-west (as for example in the neighbourhood of Exeter), and in Wales.

Many of the "greenstones" which now contain hornblende instead of augite, were probably once dolerites; and there is little doubt that the rock called diabase by petrologists is only the result of the alteration of some variety of basalt. It does not appear to be restricted to any geological age. These altered basalts are found in all the older rocks. Basalt of Carboniferous age occurs in Derbyshire, and abounds in Scotland. Probably many of the English basalts named above were ejected just after that epoch. The basalts near Exeter are Triassic; those in Antrim, and on the western coast of Scotland, with perhaps some in the north of England, are Miocene; while Etna, and many other volcanoes eject basalt at the present day. By its decomposition it generally produces an excellent soil, though projecting knolls of the rock itself are commonly arid and barren; but the principal economic value of basalt is for road-metal and paving sets. It is occasionally used as a building stone, and the long columns found in the Siebengebirge, near Bonn, are employed for posts by the road-side. Now and then, especially in ancient times, it has been sculptured, as in Egypt and in Eastern Palestine. Readers of Browning will remember the words of the dying bishop as he "orders his tomb in St. Praxed's Church":—

> "And I shall fill my slab of basalt there,
> And 'neath my tabernacle take my rest
> With those nine columns round me, two and two .
>
> . . . .
>
> Did I say basalt for my slab, sons? Black—
> 'Twas ever antique black I meant!"

* If A B be the side of a figure, P any point in it, O the centre, then (as is well known) a force acting at P, in the direction P O, may be replaced by two, one acting in the direction P A, the other in the direction P N, at right angles to P A. Of these the latter only is effective in rupturing. By a mathematical process, the total amount of all these components, for every point in the sides of a figure can be calculated, and is found to be greater in the hexagon, and least in the equilateral triangle.



THE BOTTOM OF THE SEA.

By P. Herbert Carpenter, M.A.,

Assistant Master at Eton College, formerly of the "Lightning," "Porcupine," and "Valorous" Expeditions.

"Full many a gem of purest ray serene,
The dark, unfathomed caves of ocean bear."

To most of us the bottom of the sea is altogether an unknown region. Its very nature quite precludes the possibility of our ever making a direct personal examination of it, and of the wonders it has to show. Even the most practised of the Greek sponge-divers is unable to work in water which is more than forty fathoms deep,* while the average depth of the sea is somewhere about two thousand fathoms. Little as we know about this vast submarine region directly, we are slowly, but steadily acquiring a great mass of information about it, by indirect methods. We cannot go to it, but we can cause parts of it to come to us—infinitely small, however, in proportion to its enormous extent—and we can then examine them at our leisure. Samples of the "bottom" are obtainable in small quantities by the sounding machine, and in larger quantities by the trawl, or the dredge. These last-named instruments are additionally valuable because they also bring up specimens of the animals living on the sea bed, about which we should otherwise know little or nothing.

The use of the instruments mentioned above has revealed to us that the sea covers a vast region which is, to a certain extent, comparable with the land. It has its hills, valleys, and great undulating plains. It has its various soils, widely different materials, laid down and accumulated in different places. It has its climates, also very different in different places; and it has its special races of inhabitants, which depend, like the inhabitants of the rest of the world, upon the conditions of climate, and upon the nature of the soil, or sea "bottom," on which they live.

I propose now to deal with these subjects in succession, viz., the depths and climates of the sea, the nature of its "bottom" in different localities, and lastly—in another paper—with the nature of its inhabitants, both animal and vegetable.

The superficial area of the globe is about 197 millions of square miles, some three-quarters of which—viz., 140 millions of square miles—are covered by sea. The average depth of this enormous extent of sea is given by Sir Wyville Thomson, as 2,500 fathoms, or 15,000 feet—something less than the height of Mont Blanc. This estimate, however, probably refers only to the average depth of the great oceans, for a writer in the *Naturforscher*, who has reckoned in the gulfs and inland seas as well (some of which, such as the Baltic, North Sea, &c., are quite shallow), estimates the average depth of the whole sea at 1,877 fathoms. The greatest depth yet certainly known is in the North Pacific Ocean. H.M.S. *Challenger* sounded in 4,575 fathoms—not quite five and a quarter miles—in the channel separating the Caroline and the Ladrone Islands; while there are several spots to the east of the islands of Niphon and Yezo (Japan) where the depth exceeds 4,000 fathoms, and another similar one close to the most westerly of the Aleutian Islands. The U.S. surveying ship *Tuscarora* has indeed sounded off the east coast of Japan, without finding bottom in 4,655 fathoms, but the depth may not really have been as great as this, owing to currents in the water causing loops to form in the sounding line. Unless the sounding tube brings up a specimen of the bottom, or bears other evidence of its having been there, no "sounding" can be considered as thoroughly satisfactory and trustworthy. The depth sometimes increases very suddenly. Thus the *Challenger* found between the Admiralty Islands and Japan that the depth was suddenly more than doubled, increasing all at once from 2,000 fathoms on each side, to 4,500 fathoms, which would indicate the contour of the bottom in this locality as a deep submarine valley with very steep sides. The Atlantic is by no means so deep as the Pacific, its average depth being estimated by Sir Wyville Thomson at a little over 2,000 fathoms. Its deepest part is in an area four hundred miles long, extending along the meridian of 65° W. longitude, and reaching 3,875 fathoms a little to the north of the Virgin Islands. The general contour of its bed is described as follows by Sir Wyville Thomson:—

"An elevated ridge, rising to an average height of about 1,900 fathoms below the surface, traverses the basins of the North and South Atlantic, in a meridional direction from Cape Farewell, probably as far south at least as Gough Island, following

* "Science for All," Vol. I., p. 58.

roughly the outlines of the coasts of the Old and New Worlds. A branch of this elevation strikes off to the south-westward about the parallel of 10° N., and connects it with the coast of South America at Cape Orange; and another branch crosses the eastern trough, joining the continent of Africa probably about the parallel of 25° S. The Atlantic Ocean is thus divided by the axial ridge and its branches into three basins: an eastern, which extends from the west of Ireland nearly to the Cape of Good Hope, with an average depth along the middle line of 2,500 fathoms; a north-western basin occupying the great eastern bight of the American continent, with an average depth of 3,000 fathoms; and a gulf running up the coast of South America as far as Cape Orange, and open to the southward, with a mean depth of 3,000 fathoms."

Let us now turn to the subject of ocean temperature. It is, I suppose, pretty generally known that our ideas as to deep-sea climates have undergone a very remarkable change during the last few years. Up to 1868 it was commonly thought that the temperature of the sea at any considerable depth was uniform all over the globe. Sir John Herschel stated, in his "Physical Geography," that "in very deep water all over the globe a uniform temperature of 39° Fahr. is found to prevail." This doctrine was based partly on the temperature-soundings taken in Sir James Ross's Antarctic expedition, and partly on other temperature-soundings which seemed to agree with them. It was, however, rudely shaken by the results of the *Lightning* soundings in the North Atlantic in 1868. This series of careful observations revealed the fact that the bottom temperature is by no means uniform at 39° Fahr., but that even within a few square miles there may be great differences of climate, accompanied by considerable differences in the nature of the animal life in the two localities. In the deep channel (from 500 to 600 fathoms) lying E.N.E. and W.S.W., between the North of Scotland and the Faröe banks, two very different submarine climates were found to exist. In some parts of the channel the bottom temperature was found to be as low as 30° Fahr. (*below* the freezing point of fresh water); while in other parts of it *at the same depths*, and with the same surface temperature, the bottom temperature never fell below 46°. Some animals were found to be common to both of these "warm" and "cold" areas; but, as a general rule, the shells, Echinoderms, Foraminifera, and sponges of the one were found to be quite distinct from those of the other. These facts are considerably at variance with the older notions as to deep-sea temperatures; and, although the latest researches have revealed a general uniformity of temperature in the deepest parts of the great oceans, this uniform temperature is far lower—5° or 6°, at least—than had been generally supposed.

The temperature at great depths is very low. In those parts of the Pacific, Atlantic, and Southern Sea, where the depth exceeds 2,000 fathoms, the bottom temperature is usually a little above the freezing-point of fresh water (32° Fahr.). In the deepest hollows it sinks to the freezing-point, and even a little below it; at lesser depths (except in such cases as the *Lightning* channel, which will be considered later) the temperature is higher, and increases towards the surface. Here the temperature varies with the season of the year, the latitude of the place, and other causes, being dependent to a very great extent on the amount of heat received from the sun. This heat is sufficient to produce very important differences in the temperature of the upper layers of water. It usually falls—rapidly at first, and then more slowly, down to a depth of 500 fathoms, where the temperature is usually about 45° Fahr. As the depth increases, the temperature falls very slowly and gradually to near the freezing-point, or even below it.

The climates of the inland seas may be very different from those of the great ocean basins. In the Mediterranean, for example, where the depth may reach 2,000 fathoms between Malta and Crete, the bottom temperature is uniform at about 55° Fahr. In the Sulu Sea, again, a small basin lying between the north-east angle of Borneo, the south-west promontory of Mindanao, and the Sulu Archipelago, the depth reaches 2,550 fathoms, but the bottom temperature is only 50°.5 Fahr.; while in the basin of the North Pacific the bottom temperature at the same depth is below 35° Fahr.

These differences of submarine climate admit of a very simple explanation, with which, however, we will not concern ourselves at present, as our object is merely to bring forward facts. At some future time we can discuss the theories which have been based upon them. They have served their present purpose in helping us to get rid of the doctrine that the deep sea has a uniform temperature of 39° Fahr. everywhere. Let us pass on to a consideration of the different kinds of deposit which are now being laid down on the bed of the sea.

Geology* tells us that many of the materials of

* See "Science for All," Vol. I.: "A Visit to a Quarry,"

the land masses of the world, such as sandstone, clay, chalk, and conglomerate or pudding-stone, were once deposited in layers at the bottom of the sea, where they began to assume their present form and character. Under the influence of various agencies acting in the interior of the earth, they became hardened and compressed, and finally raised up into their present condition of dry land. These deposits have a twofold origin. Many of them, such as sandstone, conglomerate, shale, and slate were formed near the shores of pre-historic seas, from the *débris* of the adjacent land, which was brought down into the sea by rivers, or worn off the coast by the action of the waves. But the rivers and the waves are not the only agents concerned in the formation of new rocks on the bottom of the sea. There is another ever active agent doing the same work, and doing it to an extent which we are only just beginning properly to realise. That agent is life, principally animal, but partially also vegetable life. Its mode, or rather modes, of working will be explained as we proceed.

We will commence our study of the sea "bottom" with a brief examination of the shore deposits, *i.e.*, the deposits which are now being formed near continents and islands. These receive their chief characteristics from the presence of the *débris* of the adjacent land. In some cases they extend to a distance of one hundred and fifty miles from the coast. Where the land contains the older and crystalline rocks the shore deposits are generally blue or green clays, containing mineral particles of different sizes, the largest being nearest the land. The shore muds also contain the remains of diatoms,* together with leaves, fruits, and pieces of wood. Large pieces of rock, such as pumice and granite, and smaller rounded pebbles, are not uncommon. The blue muds are very common along the east coast of North America, between Halifax and New York, extending to a distance of from 80 to 100 miles from the coast. At one station off Nova Scotia the *Challenger's* dredge brought up a large syenite boulder weighing 5 cwt., together with a quantity of this blue mud, from a depth of 1,340 fathoms. The bottom of the Southern Ocean, near the ice barrier, consists of blue muds very similar to those of the North Atlantic, and containing diatom cases, together with many pebbles and blocks of granite and other rocks. Similar muds are found at the bottom of all enclosed seas, such as the Arafura, Banda, Celebes, and China Seas, and the Inland Sea of Japan. Along the east coast of South America, the shore deposits, which extend down to 2,000 fathoms, are peculiar from their red colour. This is probably due to the quantity of ochreous matter carried into the sea by the South American rivers. Near volcanic islands the presence of the *débris* of volcanic rocks gives a distinctive character to the shore deposits, which are generally grey muds and sands containing pieces of pumice, scoria, &c. These deposits are found as deep as 2,500 fathoms, and sometimes extend to great distances from the islands, 200 miles, for instance, from Hawaii. In the neighbourhood of coral reefs the deposit is a calcareous mud with broken pieces of coral and large foraminiferal shells. All the deposits about Bermuda are of this nature, extending from the edge of the reef down to a depth of 2,650 fathoms. At 1,000 fathoms the mud assumes a rosy tinge, which deepens into a red colour as the depth and amount of clayey matter increase; and the amount of carbonate of lime decreases in proportion, until finally the coral mud, which contains very few mineral particles, passes into the red and grey deep-sea clays of the surrounding ocean. In other places, however, as the Admiralty, Sandwich, and Virgin Islands, Tahiti, Fiji, &c., the coral muds form a narrow band round the land, rarely at a greater depth than 600 fathoms, and usually containing a considerable admixture of mineral particles and clayey matter.

Extensive as are the shore deposits now forming on the ocean bed out of the materials derived from the disintegration of the land, they cover but a small area in comparison to those "oozes" which owe their origin to the agencies of animal or vegetable life. More than twenty years ago it was discovered that over a great part of the North Atlantic Sea bed a very remarkable deposit is being formed, a deposit now known as "Globigerina-ooze." Recent systematic exploration of the deep sea has revealed the extension of this ooze over enormous areas of the bottom. It consists of an aggregation of very minute shells belonging to the group which is known as *Foraminifera*,† since the shells are generally pierced with numbers of small holes, through which long feelers are extended by their tiny inhabitants. By far the largest proportion of the foraminiferal shells in the deep-sea ooze

pp. 66-9; "A Piece of Limestone," pp. 12-4; and "A Piece of Slate," pp. 342-3.

* See "Science for All," Vol. II., "Dust," p. 277.

† "Science for All," Vol. I., pp. 10, 14, 66; Vol. II., p. 277.

belong to the type known as *Globigerina* (Fig. 1). It forms a minute shell from one-twentieth to one-thirtieth of an inch in diameter, and composed of several little globules or chambers piled up one on another, with a rough surface pierced by a number of minute pores. These globigerinæ spend a great part, possibly the whole, of their lives on the surface of the sea, and eventually sink to the bottom, where their shells accumulate in countless numbers (within certain limits of depth), and form about 85 per cent. of the ooze. They occur on the surface of all seas, from the equator to the Polar ice. They are more abundant, more varied in character, and of a larger size in the warmer seas; being smaller, less numerous, and less varied in high latitudes, but one kind only occurring south of the latitude of Kerguelen's Land. There is also a great difference between the appearance of the globigerina-shells captured on the surface of the sea by the tow-net, and that of those brought up from the bottom by the dredge. The surface forms have very thin-walled shells, clear and transparent, with very distinct pores, and their whole surface is covered with a forest of spines,

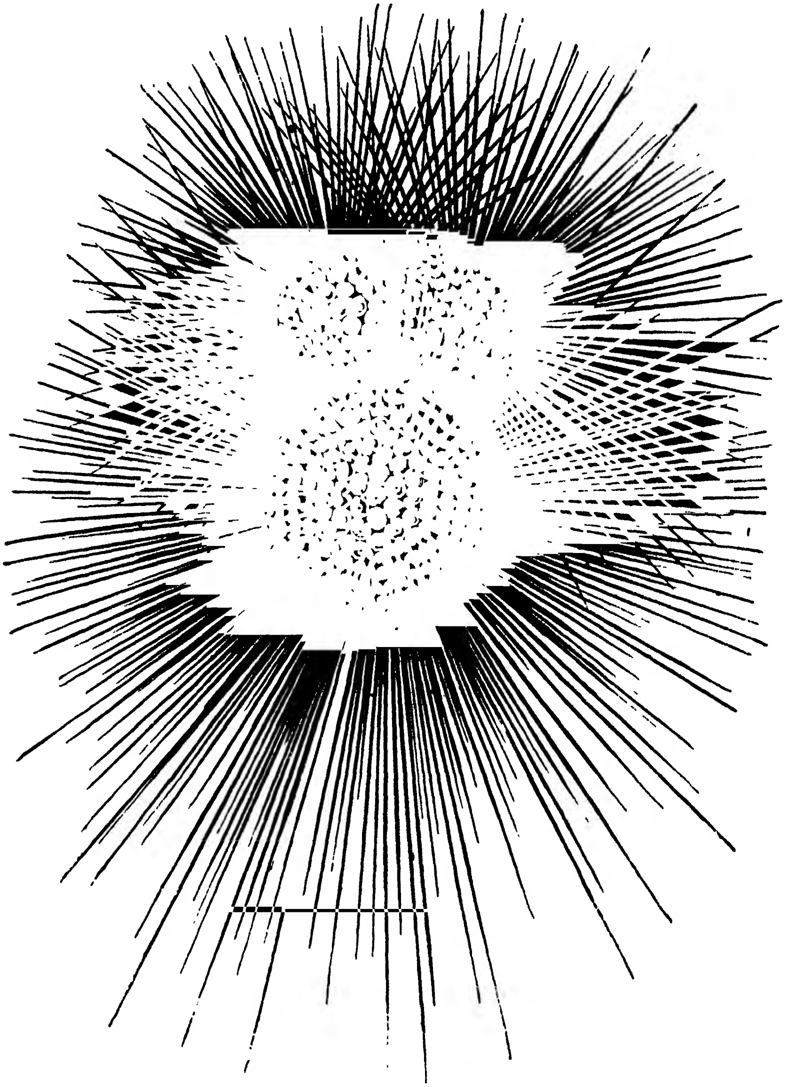


Fig. 1.—Globigerina Bulloides from the Surface. (*After Sir Wyville Thomson.*)

often four or five times the diameter of the shell in length, which radiate symmetrically from the direction of the centre of each chamber. The shell has a tiny animal in its interior, which is nothing but a particle of gelatinous material, like the white of egg, and is known as sarcode or protoplasm. When alive and uninjured this protoplasm exudes gradually through the pores of the shell, spreads out on its surface and up to the end of each of the spines, where it absorbs minute particles of organic matter floating in the water. These protoplasmic sheaths of the spines are in a state of continual flowing movement, creeping up one side and down the other, and carrying along in the stream the food particles which they have taken in. Similar flowing movements may be seen in the protoplasm of the *Amœba* or "Proteus animalcule," and in the cells of many plants, such as *Chara, Valisneria,* &c. They are eminently characteristic of living protoplasm, whether animal or vegetable.*

The dead globigerina-shells brought up by the dredge from the deep-sea bed are usually much larger and thicker than those of the living forms from the surface water. This change in external appearance is due to a supplementary limestone deposit upon the outside of the proper chamber-walls, so as completely to mask the shell-pores. This deposit is not only many times thicker than the original chamber wall, but it often contains

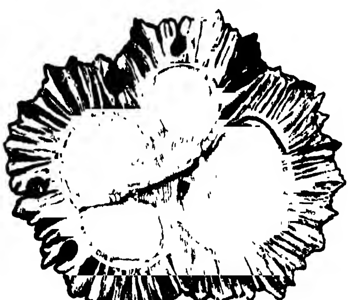


Fig. 2.—Section of Shell of *Globigerina* from the Bottom Ooze, showing the Supplementary Deposit outside the original Chamber-wall. (*After Dr. Carpenter.*)

flask-shaped cavities (Fig. 2) opening externally, and containing sarcode like that which fills the chambers. It adds very largely to the weight of the shell which, in the surface forms, is somewhat reduced by the presence of oil-globules in the protoplasmic contents; but in course of time the external deposit becomes sufficiently thick to sink the shell after death, at any rate, if not before. For it is just now a disputed point whether the globigerinæ live at the bottom at all, or only on the surface and down to a comparatively slight depth. Associated with globigerina in very variable proportion, both on the surface and in the bottom ooze, is a small spherical shell known as *Orbulina*, the exact nature of which is still doubtful. Like globigerina, it is most fully developed and most abundant in the warmer seas. Not one was detected in the icy sea to the south of Kerguelen's Land, although globigerina was constantly taken in the tow-net. Together with these forms, both living on the surface, and dead, with their shells in various stages of decay, at the bottom, there are two varieties of another foraminiferal animal, *Pulvinulina,* which is almost as abundant as globigerina in the ooze of the axial plateau of the North Atlantic, but disappears gradually towards the Southern Sea. The very pure calcareous formation in the neighbourhood of Prince Edward Island and the Crozets consists almost entirely of *G. bulloides;* while, as in the case of *Orbulina,* no *Pulvinulina* has been found south of Kerguelen's Land.

Besides foraminiferal shells, the "Atlantic ooze" frequently contains a considerable proportion of fine granular matter (sometimes as much as 20 per cent.), which fills the shells and the interstices between them, and forms a kind of cement. Microscopic examination of this substance shows that it consists almost entirely of a multitude of extremely minute calcareous particles of a rounded, oval, or rod-like form, which are known as "coccoliths" and "rhabdoliths." They are the separated elements of the peculiar armatures covering little spherical bodies known respectively as "coccospheres" and "rhabdospheres" (Fig. 3), the real nature of which (probably vegetable) is still uncertain. They live at the surface and at intermediate depths, sinking to the bottom after death, and have a very wide but not an unlimited distribution. To the south of the Cape of Good Hope they rapidly decrease in numbers both on the surface and at the bottom, so that the proportion of their remains in the globigerina-ooze near the Crozets and Prince Edward Island is extremely small. The ooze of the North Atlantic, in about the same latitude, is also nearly free from coccoliths and rhabdoliths.

In some localities this calcareous ooze also contains the siliceous spicules of sponges† and the remains of organisms with siliceous shells, both animal—such as the Radiolarians and the newly-discovered "Challengerida"—and vegetable, namely, the cases or frustules of diatoms.‡ In other localities these

* "Science for All," Vol. I., pp. 176, 295, 378.

† "Science for All," Vol. I., p. 56. ‡ Vol. II., p. 277.

remains are almost entirely wanting. Various mineral particles are also met with in the ooze, more particularly in those parts which are nearest land.

Next to the deep-sea clays (hereafter to be described), the globigerina-ooze or the "Modern Chalk"* is the most abundant deep-sea deposit. It does not occur in any of the enclosed seas, nor in the Southern Ocean south of lat. 50° S., nor in the Pacific north of lat. 10° N. Elsewhere it occurs in irregular patches at all depths from 250 to 2,900 fathoms, being always present in the open ocean at depths less than 1,800 fathoms. Its presence or absence at greater depths than this depends on conditions which are at present unknown. In the Atlantic it covers the ridges and elevated plateaus below 400 fathoms, and occupies a belt at depths down to 2,000 fathoms round the shores outside the line of shore deposits, while the deep east and west depressions are covered by a peculiar red clay. The extreme bathymetrical limit of the pure characteristic globigerina-ooze is somewhere about 1,800 to 2,000 fathoms. In certain localities, where the depth exceeds this limit, the shells gradually lose their sharpness of outline, and become more and more mixed with a fine red-brown powder, which increases steadily in proportion until the lime has almost entirely disappeared. In fact, as the water deepens the ooze gradually becomes less and less calcareous, passing into, and being replaced by, an extremely fine and pure red clay. This consists of a compound of iron, flint, and alumina, and occupies (generally speaking) all depths below 2,500 fathoms. Here and there, however, the "grey ooze," which is the intermediate condition between globigerina-ooze and red clay, is found at depths greater than this.

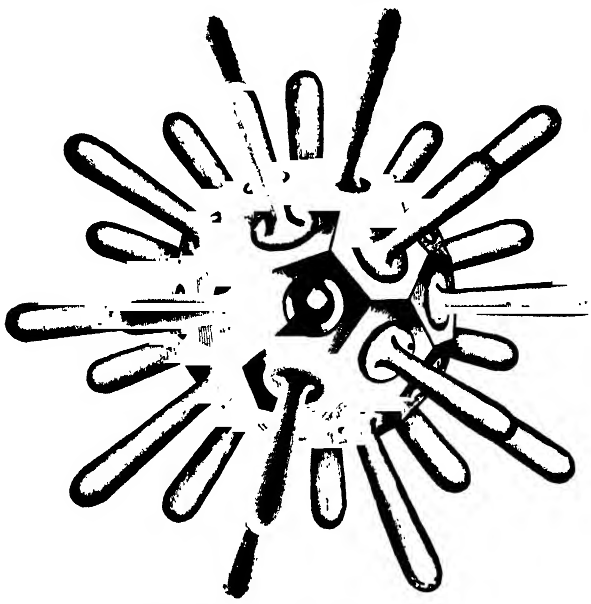


Fig 3.—A "Rhabdosphere," from the surface, 500 times natural size. (*After Sir Wyville Thomson.*)

Thus the deepest Atlantic sounding (3,875 fathoms), and several others of over 2,500 fathoms, between the Azores and Bermuda, and Bermuda and St. Thomas, respectively, showed a "bottom" of grey ooze, and not of red clay.

Nevertheless, this red clay has an enormous geographical extension. Along the section of the Atlantic sea-bed, between Teneriffe and Sombrero, the *Challenger* found 1,900 miles of red clay as compared with 720 of globigerina-ooze. The red clay also covers a very large part of the bottom of the Pacific, particularly in its northern basin, where there is a great depth of water. Much of it is probably derived from the decomposition of pumice and other minerals containing felspar,† which have reached the sea by the disintegration of volcanic rocks. Pumice is simply the upper part or froth of the lava thrown out from volcanoes, and is often light enough to float on water. It occurs more or less abundantly on the surface of the sea in all parts of the world; and after a time, when it becomes water-logged, it falls to the bottom, where it is found, in various stages of decay, over a large part of the sea-bed, more especially in the neighbourhood of volcanic centres. It occurs in pieces of various sizes, from that of a pea to that of a football, and is particularly abundant in the red clay area. Its disintegration is probably an important source of the clayey matter found in oceanic deposits; but we do not as yet quite understand the precise relations of the red clay to the globigerina-ooze. Why, for example, does the ooze usually disappear at depths much over 2,000 fathoms, and become replaced by this extensive deposit of clay? For the globigerina-shells are universally distributed on the surface, and they ought to reach the bottom at 2,500 fathoms almost as easily as they do when the depth is six or seven hundred fathoms less. On the other hand, what causes the clayey matter, which is presumably scattered almost equally

* "Science for All," Vol. I., p. 14.

† "Science for All," Vol. I., "A Piece of Granite," pp. 248–250.

throughout the sea water, to form such vast aggregations as we know of in the Pacific, and not be more evenly distributed over the ocean bed?

There is another curious fact relating to the red clay. It nearly always contains nodules of almost pure peroxide of manganese, which vary in size from minute grains to large masses, several pounds in weight, and sometimes occur in enormous quantities. They generally contain a kernel round which the mineral has accumulated, either a fish's tooth, a bit of sponge, or some other substance. Although the manganese is most abundant in the red clays, it also occurs in the other oceanic deposits, especially at depths exceeding five hundred fathoms, and Mr. Buchanan, the chemist of the *Challenger*, has recently made the singular observation, that the mud at the bottom of certain parts of Loch Fyne (the deepest portion of the Firth of Clyde) only 104 fathoms deep, contains manganese nodules identical with those which were found by the *Challenger* to form so important a constituent of the sea bottom at the greatest depths. The origin of these manganese nodules has yet to be cleared up, but there is reason to hope that the microscopic examination of them which is now proceeding will throw much light on this curious subject.

The purest and most characteristic form of the red clay is found between depths of 2,500 and 3,000 fathoms. Below this limit it contains a larger and larger proportion of the flinty shells of Radiolarians (Figs. 4, 5), which become larger and more numerous as the depth increases, while the calcareous foraminifera diminish in size and number. This is probably due to the greater depth of water, as the Radiolaria seem to live all through the sea down to its greatest depths, and not merely at or near the surface, so that the deeper the water, the greater would be the accumulation of their shells on the bottom. Consequently when the depth is enormously increased, the deposit of flinty shells must gradually gain upon that of the red clay, and finally mask it. Thus in the deepest sounding made by the *Challenger*, 4,575 fathoms in the channel separating the Caroline and Ladrone Islands, the red clay formed a kind of cement, binding the shells together; and wherever the depth reaches 4,500 fathoms, the bottom deposit is almost purely organic in nature, consisting, however, of siliceous and not calcareous shells.

As this "radiolarian-ooze" is formed only at very extreme depths, it necessarily occurs more or less in patches over the bottom of the sea, chiefly in the western and middle Pacific. It is a pale, straw-coloured deposit, almost entirely composed of the remains of siliceous organisms, the Radiolarians preponderating, though a small proportion of diatoms is also present. These diatoms, minute plants which have flinty coverings, are extremely abundant on the surface of the Southern Sea. After death their cases fall to the bottom and form a deposit here, which, when brought up in the dredge is singularly like chalk to the eye, though it is siliceous, and not calcareous in nature.*

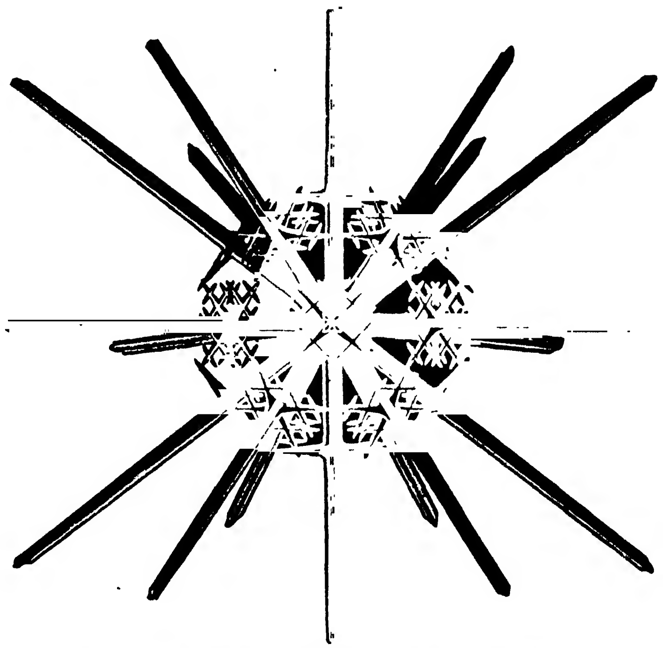


Fig. 4.—A Radiolarian (*Xiphacantha*) from the Surface. 100 times natural size. [The skeleton only.] (*After Sir Wyville Thomson.*)

The two last mentioned oceanic deposits, viz., the radiolarian-ooze, and the diatom-ooze, are two amongst the many novelties discovered by the *Challenger* expedition, another result of which (besides the discovery of the grey ooze and red clay) is a great extension of our knowledge respecting the geographical distribution of the globigerina-ooze. All these three deposits are produced by the agency of life, though of a very humble kind. The diatoms are some of the lowest plants, while both the radiolarians and globigerinæ are

* "Science for All," Vol. III., p. 21.

among the very simplest members of the animal kingdom, and yet they are instrumental in producing truly gigantic results. The chalk which shells upon it from the surface, just in the same way as globigerinæ, radiolarians, and diatoms are now falling to the bottom of the Atlantic.

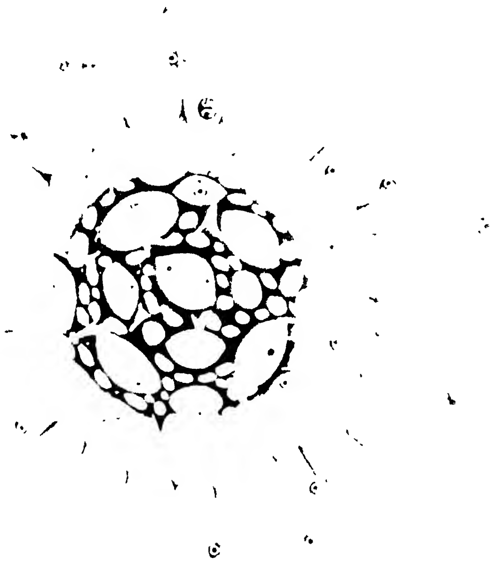


Fig. 5.—Cyrtidosphaera Echinoides, a Radiolarian captured on the Surface of the Sea at Nice.
In the centre is seen the perforated flinty Shell with its Spikes (a) radiating from it. It is clothed in the Protoplasm containing little yellow Globules (i and sending out numerous thread-like "Pseudopodia" (p). The specimen is 400 times enlarged. (*After Haeckel.*)

forms the white cliffs of Dover, and the rolling downs of the south-east and other parts of England, was once formed upon the sea-bottom by a rain of

Truly indeed may this be considered an apt illustration of the old proverb: "Small beginnings make great ends."

MARS.

By W. F. Denning, F.R.A.S., F.M.S.

At intervals of about two years a bright red star becomes conspicuously visible in the firmament throughout the night, and remains thus favourably in view for several months together. Then, setting earlier each time it falls to the horizon, and gradually becoming less brilliant, it is seen for a portion of the night only until, after the lapse of a few more months, it may scarcely be discerned at all, for now, immersed in the twilight and setting in the early evening, the nocturnal sky loses one of its brightest ornaments. This is the planet Mars, which, arriving at opposition to the sun once in little more than two years (or, more exactly, 780 days) attains considerable brilliancy, and becomes noticeable as a singularly interesting object in his bright ruddy splendour. But in different years the appearance of Mars, as seen by the naked eye, undergoes great variations, because the distance of the planet from the earth (an element upon which his apparent lustre almost wholly depends) is not the same at each successive opposition. Thus it happens that when Mars is near the earth and sun (or in perigee and perihelion) which occurs once in four synodical revolutions, equivalent to above eight and a half years, he shines with remarkable intensity, and sometimes rivals the brilliancy of Jupiter. It is,

however, only at epochs of about fifteen years that the planet is observed shining with his maximum lustre, and very well situated for examination in a telescope. In 1845, 1862, and in 1877, Mars was seen under peculiarly favourable circumstances, and in 1892 the conditions will recur again. At his apparition in 1719 he shone with such striking grandeur as to cause great alarm among the peasantry of France, who discerned all sorts of ill-omens in the fiery-red light he cast upon them. This planet was justly celebrated during the historic period on account of his imposing appearance in the permanent markings of irregular outline invariably visible every time the planet becomes conveniently placed for observation. That these lineaments are something more than mere atmospheric appearances is evident beyond doubt by their constancy. No matter how great the difference of time at which they are examined, they are seen to retain the same forms, in fact, the same identical features are manifested again and again, though, of course, not with equal distinctness. This arises simply from the fact that they are not seen under precisely similar conditions. When the planet is in that

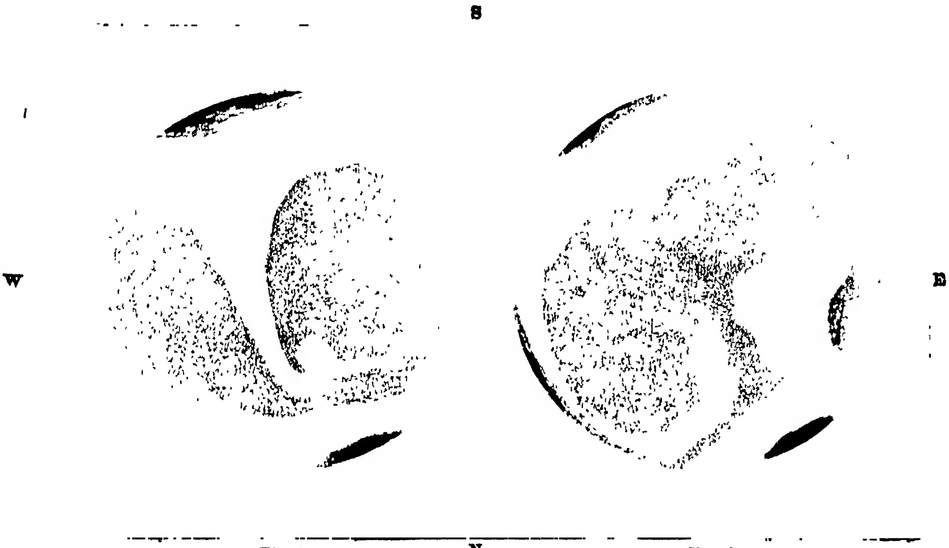


Fig. 1. Fig. 2.

Figs. 1 and 2.—The Markings on Mars.

heavens. To the Jews he was familiarly known under a title analogous to "blazing," and the Greeks gave him a similar appellation in πυρόεις. Yet Mars is not comparable with Venus in point of brilliancy, and is very seldom as conspicuous as Jupiter. At his last favourable appearance in 1877 (which was one of the most noteworthy on record, being signalised by the discovery of his two satellites), the planet could be well compared with Jupiter visible at the same period in the evening sky, but there could be no doubt that the jovian planet surpassed his rival. We can, however, readily understand that in past ages Mars, with his intense blood-red lustre, would be certain to attract much notice, and instil dread into the popular mind.

By means of the telescope astronomers have been enabled to distinguish varieties of light and shade upon the surface of Mars. There are certain part of his orbit nearest to the earth his apparent diameter is greatest, and obviously the markings on his disc will be exhibited very favourably for inspection. Again, our own atmosphere will occasionally allow very excellent views of celestial objects, while at other times little or nothing can be seen through its moisture-laden strata. Moreover, the inclination of the planet's axis originates apparent changes in the forms of the markings at different oppositions. Sometimes the southern hemisphere is chiefly presented to view, and sometimes the northern. The true figure of a marking cannot be distinguished unless it is seen at the centre of the apparent disc. Spots near the margin are contracted by the effects of foreshortening. Such differences, therefore, as are observable in the aërographic appearance of Mars are in no way attributable to changes on his surface, but have their origin in his varying distance, and in

atmospheric causes. The dark and light objects which diversify his disc are really permanent features existing on his globe, and though they may often be a little dimmed by atmospheric interference (just as we may imagine that, to an observer on Mars, the continents and seas of the earth are partially shrouded by the clouds in our own atmosphere), yet they invariably reappear with former distinctness, exhibiting precisely similar shapes to those depicted in past years.

Figs. 1 and 2 are views* of Mars selected from a large number of sketches made by Mr. Nathaniel Green in 1873, with a reflecting telescope of 9 inches aperture, and magnifying powers of from 200 to 400. In Fig. 1, that prominent marking, the Kaiser Sea (connected with Dawes Ocean in the southern hemisphere, and projecting towards the Delambre Sea in the northern hemisphere) is well shown as a latitudinal hand tapering at its northern extremity, and curling up as it turns eastwards. In Fig. 2 the planet's rotation has carried the Kaiser Sea to the western margin of the disc, and another conspicuous though more diffused shading has entered well into view. This is the Knobel Sea, and on the southern limb that dark irregular marking, the De la Rue Ocean, is very distinctly marked.

The character of the spots on Mars gives the impression of land and water. The brighter regions of the surface are orange-coloured; the darker spaces, which vary a good deal in depth of shading, are greenish, possessing the aspect of a fluid by which the sun's rays are absorbed. Hence, it is to be inferred that the latter parts represent seas and the former land. If this is so there is considerably more land than water in Mars. The form and distribution of his chief features have been carefully mapped, and that they might be conveniently referred to, have received distinctive titles, so that we are enabled to refer to them with the same aptitude as we may refer to the features of the earth on a terrestrial globe. The names of eminent astronomers have been selected as the most suitable titles to the Martian continents and seas, and we are getting familiar with "Dawes Ocean," "Kaiser Sea," "Mädler Continent," and the other conspicuous parts of his surface.

But the most remarkable details revealed by our telescopes consist of two white markings, one at each pole. A number of observations of these singular appearances lead to the supposition that they are masses of snow or ice accumulated in the polar regions of the planet. This theory of their origin is strikingly supported by observation, for it has been found that under the sun's powerful action, in the summer months of Mars, the polar snows diminish in extent, while during the progress of winter they again become augmented. In fact, the variations assigned to these objects occur at such periods and in such positions as accord exactly with the accepted theory of their nature. They were first seen and figured as early as 1704, but they had probably been detected at a much anterior date, for such prominent objects could not long evade the scrutiny of the telescope. A very singular though well-attested fact in connection with them is that they are not exactly opposite to each other. This apparent anomaly is not readily explained, though it has been suggested that on Mars, as on the earth, the poles of cold do not correspond with the poles of rotation.

The southern snow region, as observed and delineated on September 8th, 1877, at 12.30 p.m., is shown in Fig. 3. The two white spots on

Fig. 3.- South Pole of Mars.

the western side have been named the Mitchel Mountains, the inference being that they are the snow-crowned summits of lofty elevations situated just outside the polar snow-space. In the views of the latter formation by the Italian observers in 1877 the appearance is remarkably different, consisting of a small triangular patch slightly within the south border of the disc.

The delineations of Mars, though agreeing in the main, are yet in some respects strangely dissimilar. The various forms of telescope employed, the different epochs of observation, the differences in vision, and the manner of depicting and interpreting what is seen, all contribute to create discordances amongst the results. Yet, as has been said, in the main the general facts are accordant, and observers have at times confirmed each other in an astonishing

* Reproduced here by the kind permission of the Editor of the *Astronomical Register*.

degree, so that at the present day there can be no doubt as to the form and extent of the principal markings on Mars. Physical changes have been inferred, but none are proved to have occurred. During the last favourable appearance of Mars in 1877, the Italian astronomer Schiaparelli recognised a number of dark, narrow channels or canals intersecting the planet's equatorial zone, and these he had not seen before October in that year, nor had any other observer distinguished them at any previous date. It seems, however, a probable inference that these irregular lines of shading are to be referred to instrumental or visionary errors, for in the more powerful telescopes directed to the planet's disc at the same period, no traces of these remarkable appearances were seen, and it has been adduced in explanation of the observed peculiarities, that minute dusky shadings will, with bad definition, apparently become lines, especially when several lie nearly together. The canals or channels supposed

Fig. 4.—Suspected Canals on Mars.

to have been distinguished by the Italians are represented in Fig. 4 (planet in long. 0°, lat. 25° S.).

That Mars has an atmosphere appears extremely probable, for such an envelope is implied in the formation of snow. It is, however, likely to be only moderately dense, and does not originate the intense ruddy tinge of the planet's light as some have believed, for this is most decided in the region about the centre of the disc. Obviously the red colour would be deepest on the margin, were it attributable to the planet's atmosphere. Moreover, it has been ascertained that Mars always looks reddest when his atmosphere is clearest, and the various markings upon his disc come out with great distinctness, and it is a notable fact that the colour never affects the snow masses at the poles, which invariably present a dazzling whiteness.

But it would appear that there are no clouds of any intensity and extent upon the surface of Mars, because his chief markings are always easily identified. Certainly, in the equatorial region of the planet no really dense clouds have ever made themselves evident. The opacity of our terrestrial atmosphere is such, that remarkable differences must be observable in our appearance as viewed from Mars. Tracts of land will be utterly hidden from view, and the constantly varying forms of cloud phenomena will be interesting to witness and difficult to account for. Above the surface of Mars, however, there are no cloud masses to obliterate the outline of his land and sea, though an atmosphere and its modifications are necessary to the existence of the snow patches and other features supposed to be common to his globe. But there is evidence to show that occasionally certain parts of the planet are rendered faint, and, indeed, a few instances are recorded in which the features were entirely obscured. On September 29th, 1877, at 9h. Mr. Green, at Madeira, saw the outline of the De la Rue Ocean on Mars hidden by cloud on the planet. On September 18th there were manifest signs of the breaking up of the snow-zone around the south pole, and its great indistinctness at this epoch was especially noted by several observers. And in 1877 and 1862 portions of Dawes Ocean were sometimes hidden by a light not constantly hanging over that region of the surface. Occasionally, too, white patches have been glimpsed on the margin of the disc, chiefly on the eastern side, and as these objects remained upon the limb the inference is, that they were exterior to the surface and originated by masses of cumulus clouds or mists upon the planet. But to be thus observable their volume must be very considerable, and far beyond the extent and character of what we have been led to understand of the atmosphere of Mars.

It was by means of the spots observed on this planet that his period of rotation became an element easy of determination. On the morning of February 6th, 1666, the astronomer Cassini, surveying Mars through a telescope sixteen feet long, was astonished to behold two dusky spots on his disc. He looked for them again on subsequent nights, and his diligence was rewarded by their re-appearance. Noting their positions attentively as they gradually passed across the planet to his western margin, and re-observing them as they came into view on the opposite limb, he was enabled to fix the rotation as performed in 24 hrs. 40 mins., which differs very slightly from the period now adopted, viz.: 24 hrs. 37 mins. 23 secs. But Cassini appears to have been

anticipated in these discoveries by Huygens, who approximately discovered the rotation in 1659.

Thus the length of a day on Mars is but slightly in excess of the duration of a terrestrial day, though his year extends over 669 days, and his seasons in the northern hemisphere are unequally distributed in the following proportions:—Spring 192 days, summer 180, autumn 150, and winter 147 days.

Mars is only about twice the dimensions of the moon, and little more than half the size of the

Fig. 5.—Relative Size of Mars and the Earth.

earth. In Fig. 5 if the circle E represents the earth, then M is the proportionate size of Mars.

Though no satellite had formerly been discovered accompanying Mars in his revolutions, it was conjectured that one might exist, but of such small dimensions as to elude the greatest power of our telescopes. Being a very small planet, it was a natural inference that his satellite must be proportionately minute. That it had never been seen, was not conclusive proof of its non-existence, and it was further argued that the analogies of the solar system strongly suggested that Mars might have a moon, because satellites have been apparently supplied to the planets in increasing numbers, as they recede from the sun; and if the analogy held good in the case of Mars, he must be provided with two satellites, seeing that his orbit lies outside that of the earth, which possesses one moon; yet such bodies, had they any existence, had evaded detection through the long lapse of nearly three centuries since the invention of the telescope. It was hardly to be expected that the old astronomers, with their imperfect and rudely-devised instruments, would ever catch a glimpse of them, but in more recent times it was difficult to see how the gigantic mirrors of Herschel, Rosse, and Lassell, or the large object glasses of Bond in America, and of the eagle-eyed Dawes in England, had failed to render them visible, though the keenest scrutiny had been directed again and again, to the planet's side, with that object in view. These failures brought discouragement. Evidently an increase in telescopic power was needed, or what was of equal importance, a very favourable position of Mars must be awaited, before the discovery of his moons could be looked upon as feasible.

Now it was known that in 1877 the planet would be singularly well placed for such observations, and Professor Hall, of the Naval Observatory at Washington, having a very fine refracting telescope of twenty-six inches aperture under his direction, resolved to make renewed search for the suspected satellites, though at the very outset he confessed to a want of confidence as to success. Looking at the mass of negative results obtained by skilful astronomers in the past (especially by Sir W. Herschel in 1783, and D'Arrest in 1862 or 1864) he had little hope of the realisation of his desires. Nevertheless, the search was begun early in August, 1877, and several small stars of the ordinary character were seen near the planet. On August 10th, Professor Hall commenced to look in the region close around Mars, and enveloped in the glare of his light, but nothing was found. The next night observations were resumed, and he ultimately detected a very faint object, which afterwards turned out to be a satellite of the planet, but before he could secure a note of its position, a fog gathered up from the Potomac River and overspread the sky; but on August 16th the satellite was recovered again, and on the ensuing night, while watching and waiting for its re-appearance, another yet fainter satellite was discovered, and the true character of the two objects being placed beyond doubt by further diligent observation, the facts of the discovery were announced to the scientific world.

The names selected for the new bodies were Deimos (Terror) for the outer satellite, and Phobos (Fear) for the inner satellite. They are remarkably close to the planet, and revolve in very short periodic times. Thus Deimos is 14,500 miles distant from the centre of Mars, and revolves around him in 30 hours 18 minutes; and Phobos, at a distance of 5,800 miles, revolves in 7 hours 39 minutes. The latter moon was at first a complete puzzle to its discoverer, for it would appear on different sides of its primary during the same night, and at first he thought there were two or three inner moons. To settle the matter, he followed this moon throughout the whole nights of August 20th and 21st, and learnt the secret of its rapidly varying positions. Revolving around Mars in about one-third of the time occupied by the planet in his rotation, its swift orbital motion

necessarily carried it from one side of the planet to the other at short intervals, and thus presented a case beyond parallel in the solar system.

Subsequently to their discovery in America, the moons were also seen by several observers in different countries. They are marvellously small and minute bodies, but their actual diameters cannot be definitely ascribed with any certainty, because they are mere specks of light incapable of measurement. Undoubtedly, these moons are the smallest heavenly bodies ever discerned by the human eye, and are solely objects for acute vision and large telescopes, and even then will be rarely seen. In the autumn of 1879, Mars being in excellent position, his satellites were glimpsed* again, but during the next ten years they will be utterly beyond the reach of the most powerful instruments ever constructed, for the planet is too distant from the earth, and we must await the year 1892 to hear of the re-observation of his moons.

The discovery of two satellites attendant on Mars adds another link to the harmony of the solar system, for, so far as our telescopes are capable of revealing, the number of moons furnished to the planets increase accordantly with their distances from the sun. Thus the earth has one satellite, Mars two, Jupiter four, Saturn eight, and if this regular increase is maintained in the cases of the outermost planets, Uranus and Neptune, they must be accompanied by a numerous retinue of such bodies. It appears highly probable that this is the case, as analogy suggests, though hitherto our telescopes have proved inadequate to the task of rendering them visible.

Mars does not exhibit phases like the superior planets Mercury and Venus. It is evident that his orbit being exterior to that of the earth, he can never be seen in a crescent shape, though in certain positions he assumes a gibbous appearance, similar to the moon when she is near the full. Galileo recognised this feature in 1610, for on December 30th of that year, he wrote to his friend Castelli, saying: "I dare not affirm that I can observe the phases of Mars; however, if I mistake not, I think I already perceive that he is not perfectly round."

The mean distance of Mars from the sun is, in round numbers, about 139,000,000 miles. Owing to the eccentricity of the planet's orbit, the distance varies between 152,000,000 and 126,000,000 miles. In Fig. 6, if S represents the position of the sun, and E 1, E 2, E 3, and E 4 the earth's orbit, then M 1, M 2, M 3, M 4, is the relative distance of Mars. At m the planet is in perihelion, and at m' in aphelion. Now when the planet is near perihelion at the time of opposition, his distance from the earth is at the minimum, and he becomes visible under very favourable conditions. His apparent diameter then subtends an angle of about 23 seconds of arc, whereas if the planet

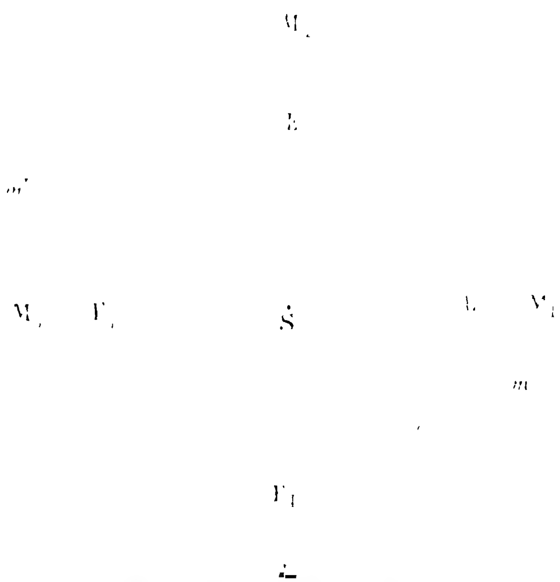


Fig. 6.—Orbits of the Earth and Mars.

comes into opposition at m' when in aphelion, the diameter is only 13 seconds, so that it is easy to understand why the successive apparitions of Mars are not all equally favourable, and why at certain epochs special efforts are made to obtain telescopic observations of his features.

There is no other planet of the solar system which offers so close an analogy to the earth as Mars. The telescope reveals to us the figures of broad tracts of land, and expanses of sea upon his surface. The durations of his day and night almost coincide with our own. His exterior experiences the alternating changes of the seasons. His nights are illumined by two satellites, which present all the phenomena of our own moon, and more frequently, owing to their greater velocity. An atmosphere probably surrounds the planet; in fact, the existence of air is indispensable to his other

* The outer satellite was seen as early as September 22nd, in the large reflecting telescope of Mr. A. A. Common at Ealing. In October he found it plainly visible.

features. Hence the inference that Mars is a habitable globe appears a very obvious and fair conclusion, and it would be inconsistent to imagine that this planet, provided apparently with all the requisite natural facilities to render life a necessary and desirable feature of his surface, is a sphere of desolation, a mass of inert matter, which, though conforming to the laws of gravitation, is otherwise serving no useful end, as the abode and sustenance of animate creatures. It is far more in accordance with analogy and rational speculation to conclude that Mars is the centre of life and activity, and that his surface is teeming with living beings. It cannot be that the sun wastes his radiant warmth upon a bleak and barren globe accompanied by two satellites that were merely devised to lighten the solitary aspect of his sea and landscape! Nor can the sequence of his seasons, or the pleasant variety of day and night be given, with no intelligent creatures to mark and appreciate the wise and ever-recurring changes. Can we picture to ourselves a planet utterly void of life, where the stillness of death and desolation has absolute supremacy, where in the weird aurora of day-break no beings are aroused to activity, and where the sighing of the wind, amid the rolling of waters, is all that breaks the monotony of time? The undulating contour of hills and valleys is there, but the place is a wreck, and one might think that earthquakes had rent and shattered the rough, uncultured condition of the surface. No vegetation is apparent, and none could subsist in that bleak and rarefied atmosphere, but the most impressive thing of all must be the solitary stillness of the surroundings. The wild character of the landscape, the cold attenuated air encompassing it, the manifest dearth on all around might be endurable, and, perhaps, tolerated for a time, but the absence of living creatures must exercise the most depressing influence of all. An unbearable sensation of loneliness and horror must take possession of a human being could he survey the death-like aspect of a world akin to this, and he would turn shudderingly away from the picture. Such conceptions as these are, however, not only repugnant to our feelings, but in direct opposition to our views of the wisdom of the Creator, who in devising the grand mechanism of the solar system, did not forget to endow the individual parts with many attractive and beneficial details. We must indeed have limited ideas to doubt the extension of life to systems beyond our own, or to question their adaptability for its suitable maintenance in some form or other.

An inhabitant on Mars will see the earth in much the same aspect as we are accustomed to observe Venus. Our planet will appear successively as a morning and evening star of considerable brilliancy, and attended closely by her satellite. Viewed in the telescope we shall exhibit phases, and so will the moon by our side, in which our exact image will be repeated, appearing sometimes as a slender crescent, then increasing until half the disc is enlightened, and finally becoming full. But the most interesting of celestial phenomena to the Martian inhabitants, if any exist, will be that presented by their two satellites, particularly Phobos, which, being less than 4,000 miles distant from the surface of the planet, may be scrutinised with great distinctness. Telescopes may reveal living creatures on either orb, for employing a power of 1,000 diameters, the objects common to the surface may be examined at an apparent distance of only four miles, from which might be detected all the more prominent features and characteristics. The outlines of buildings or trees may be discerned, and even the recognition of living beings will be possible at this distance. If the planet and its nearest satellite are both inhabited, then the mutual employment of telescopic power must result in mutual recognition, and that would doubtless lead to the adoption of a method of signalling, by which means a constant communication might possibly be going on between the two orbs. But these points are purely matters of speculation.

The earliest recorded observation of Mars found in ancient history, is that quoted by Ptolemy in his *Almagest*, wherein the date is given as the 52nd after the death of Alexander the Great, and the 476th of Nabonassar's era; on the morning of the 21st of the month *Athir*, the planet was observed slightly above, but very approximate to the star β of Scorpio. The dates correspond to the year B.C. 272, January 17th, at 18hrs. on the meridian of Alexandria. There was an occultation of Jupiter by Mars witnessed early in 1591, but that was just before the invention of the telescope, and the phenomenon may have been a very near appulse only of the two bodies. In any case the occultation must have been a partial one, because the apparent diameter of Jupiter almost invariably exceeds that of Mars, and the occurrence ought more correctly to be described as a "transit of Mars across Jupiter," as suggested by Chambers. It was unfortunate that at the epoch of this occurrence, the telescope had not come into use, for some important

observations might possibly have been obtained as to the atmosphere of Mars.

Oppositions of Mars afford a method (quite independently of transits of Venus) of deriving the value of the solar parallax, and hence the sun's distance. That this element should be very exactly determined, is of extreme importance, inasmuch as it affects other celestial measurements. The Astronomer Royal called attention twenty years ago to the fact that the opposition of Mars in 1877 would offer an eminently favourable occasion for observing Mars with a view to finding the sun's distance. This had been ascertained at 92,400,000 miles from a parallax of 8″·8455 obtained from the transit of Venus in 1874 by the British observers, and Mr. Gill finds from a preliminary discussion of his recent observations of Mars at the island of Ascension, a parallax of 8″·78.*

VISIBLE SOUND.

By Professor F. R. Eaton Lowe, M.A., Ph.D., etc.

NOT the least amongst the many marvellous results of modern scientific investigation is the employment of optical means for demonstrating the nature of sound. Before the time of Chladni, who, towards the end of the last century, discovered the method of exhibiting the phases of motion in a vibrating plate by means of sand strewn upon its surface, it would have been deemed simply unintelligible to assert that musical sounds could be distinguished through any other medium than that of the ear. Even in our own day there are many whose knowledge of acoustics has been derived from works published little more than twenty years ago, who would be equally surprised to learn that the eye, and not the ear, constitutes by far the more sensitive and delicate sound analyser. The ingenious device of Chladni was obviously inapplicable in the case of rods or strings; and it was not till nearly thirty years afterwards that Dr. Young employed a beam of light to illustrate the vibration of a pianoforte wire, and was therefore the first to introduce the optical method of giving visual expression to sound. Dr. Young, however, who died in 1829, could hardly have foreseen the extent to which the method which he had the distinguished merit of originating would be developed by his successors at home and abroad; for nearly thirty years more elapsed before Wheatstone and Tyndall in England, and Helmholtz, Melde, and Lissajous on the Continent, independently, and almost contemporaneously, devoted their special attention to this branch of physics, and by the use of the electric lamp as a source of illumination, and concave mirrors to reflect a pencil of light from the sounding body upon a screen, produced the most beautiful and startling results. By the aid of the very simple apparatus used in performing these experiments we may shut our ears while a musical note is sounding, and still recognise the continuance of the sound which has become inaudible to us. We may even measure mathematically the intensity of such sound—an operation of which the ear alone is incapable; all its phases of crescendo and decrescendo are rendered visible as a lengthening and shortening band of light; and if another note be sounded at the same time, the interval produced by the combination is represented by a luminous figure whose form is constant for the same interval under the same conditions. The slightest deviation from purity in tone is marked by a change in the figure, and its outline may be caused to undergo the most beautiful and varied modifications by simply altering the pitch of one or both of the notes under examination. Before proceeding to discuss in detail the physical laws involved in these experiments, it will be necessary to notice the mechanical device of Chladni for exhibiting the vibrations of plates, because it not only ranks first in order of discovery, but revealed new and quite unexpected acoustic phenomena of primary importance.

Chladni employed square or round plates of metal or glass, supported horizontally upon stands, to which they were clamped either at the centre or near the edge. The surface of the plate being blackened, and fine white sand scattered over it, a well-resined violin bow was briskly drawn across

* More than 200 years ago, namely, in 1672, Flamsteed endeavoured to obtain the solar parallax by observations of Mars, and succeeded approximately in determining it as less than 10″. The French soon after declared that they had found the same, for they had witnessed Mars occult the star ♈ Aquarii on October 1st, 1672, and the measures taken by three observers, enabled the late M. le Verrier to re-discuss the observations, and derive the solar parallax as = 8″·866.

its edge (Fig. 1). The sand was immediately thrown into rapid movement by the vibration thus set up, and finally arranged itself into a perfectly symmetrical figure, sometimes assuming a beautiful stellar form, at others exhibiting a system of concentric circles or semicircles; while in the case of square plates, lines running parallel to the edges or to the diagonals, were seen to intersect to produce a check or chess-board pattern. In short, the number of patterns which could be obtained was found to be almost infinite, as they were affected by a variety of circumstances, such as the points struck and damped, and the shape, thickness, and density of the plates. Some idea of their varied character may be formed from the subjoined engraving (Fig. 2).

Fig. 1.—Vibrating Plate supported

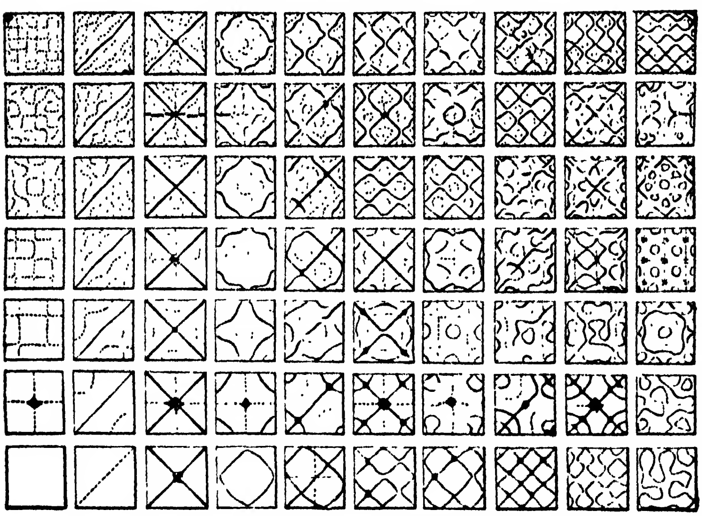


Fig. 2.—Chladni's Plates.

Chladni himself tells us that his discovery was suggested by an experiment of Lichtenberg, who demonstrated the electrical condition of an electrified resin plate by a powder strewn upon its surface.

The laws regulating the production of Chladni's sand figures will be best understood from an examination of some of the simplest forms. Commencing with square plates, we will take one clamped at the centre (Fig. 3), and damp it by lightly touching it with the finger at the middle point of one of its sides (*a*). On drawing the bow across its edge at *b*, near one corner, all the sand collects along two lines intersecting in the centre of the plate, thus dividing its surface into four squares of equal size. These two lines are the *nodal* lines, or lines of no vibration. It will be remembered that when a musical string vibrates it divides itself into segments, separated from each other by nodes, or points of no vibration. The same law holds good with our plate, but in this case it is clear that the segments cannot be separated by points, but by lines, which necessarily meet at the point where the vibration is checked by the clamp, that is to say, in the centre of the plate. When a plate or strip of metal or glass vibrates, its centre alternately rises and falls below its ordinary level. Now this happens to each of the four squares into which our plate has been divided by the aggregation of the sand, and the nodal lines always separate segments having opposite vibrations, so that in the case of any two contiguous squares, one is rising while the other is falling. It follows from this that the number of segments must always be even. We cannot have less than four, which is the simplest mode of division, and yields the fundamental or deepest note of the plate, but we may have six, eight, ten, twelve, or more segments, yielding notes which become shriller in proportion as the sub-divisions become multiplied, and the corresponding sand figures, therefore, are more complicated. Chladni had noticed that a glass plate clamped at the centre emitted sounds of different pitch, according to the place where the glass was struck. He was unable to account for this phenomenon till he was fortunate enough to hit upon the device which bears his name. It then became clear that in proportion as the number of segments increased the rapidity of the vibrations was augmented, and thus the sounds, whose production had so much perplexed him, were found to be governed by the same law as that which had already been established in relation to musical strings, rods, and pipes. The reader may remember that in the case

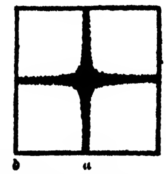


Fig. 3.—Showing vibration of Plate damped at the centre of one edge.

of a stretched wire we can cause a node to form at any point by damping that point with a feather or the finger-nail, and that, if we damp the wire at one-third, or one-fourth, or one-fifth of its length, we cause it to divide into three, four, or five segments accordingly. So, too, in our plate, any point we damp becomes the terminal point of a nodal line, and by diminishing the distance between the point damped and that struck we increase the number of segments into which the plate is divided.

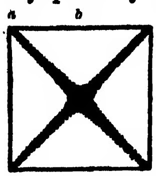


Fig. 4.—Showing Vibration of Plate damped at one corner.

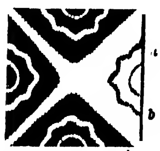


Fig. 5.—Showing vibration of Plate damped at two points.

Suppose we wish the sand to collect along the diagonals of the square instead of lines parallel to its sides, as in the experiment just performed: we have only to damp one of its corners (*a*, Fig. 4), and agitate the middle point (*b*) of one side with the bow, and the sand, with life-like sensitiveness, dances along the disc and finally settles down in the desired positions, from which it cannot be forced by any further excitation at the same point. We shall find that the note yielded by the plate is not the same as before, but a fifth above it. We can, if we please, damp more than one point, as at *a* and *b* (Fig. 5). On applying the bow to the point *c*, on the opposite side, a nodal curve will be formed on each of the four sides in addition to the diagonals as before. A more acute note indicates the increase which has occurred in the number of segments.

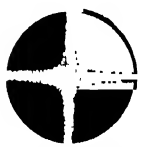


Fig. 6.—Showing primary division of circular Plate into four Sectors.

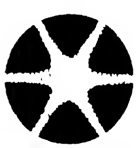


Fig. 7.—Showing second division of Plate into six Sectors.

Turning from square plates to round ones clamped at the centre, we find that the smallest number of segments is still four (Fig. 6). By setting the plate in vibration at a point forty-five degrees from the point damped, we cause the sand to collect along two of the diameters, and by striking the edge thirty degrees distant we obtain the next division of six segments (Fig. 7). Proceeding in this way, we next divide the circle into eight equal sectors, producing the beautiful star represented in Fig. 8. Besides these nodal lines in the direction of their radii, circular plates can be made to exhibit at the same time another system of nodal lines concentric with their circumference. These are produced by an impulse communicated to the centre or surface of the disc instead of the edge. A convenient way of producing them is to solder a plate to a metallic rod, and to strip or excite the rod longitudinally with the resined fingers. Some of the sand figures resulting from the combination of the two systems of vibrations are represented in Fig. 9. The thickness of these plates will affect their relative rate of vibration, for if one disc is twice as thick as another it will vibrate with twice the rapidity; but the diameter affects the rate in an inverse proportion, for if one plate has twice the diameter of another of the same thickness, it will vibrate with only one-fourth the rapidity. In technical language this law is thus expressed:—*The rate of vibration in plates is directly proportional to their thickness, and inversely proportional to the square of their diameter.*

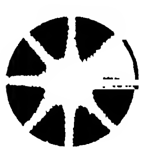


Fig. 8.—Showing third division of Plate into eight Sectors.

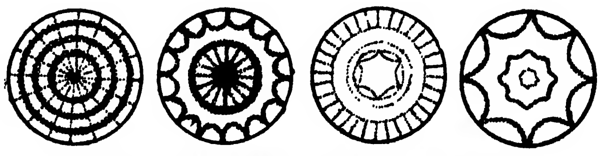


Fig. 9.—Chladni's Sand Figures: Circular Plates.

Before leaving these interesting sand figures of Chladni, we may add that the experiments involve little manipulative skill, and may be conveniently performed in a drawing-room, where they cannot fail to entertain even those who have little inclination for scientific pursuits.

The figures may be transferred to gummed paper—which should be black—and preserved in our cabinets for subsequent examination.

Fig. 10.—The Kaleidophone.

Coming now to the more strictly optical part of our subject, the *kaleidophone* of Sir Charles Wheatstone first claims our attention. It is an ingenious device for rendering apparent to the eye the path described by the end of a vibrating rod, and is a much simpler piece of apparatus than its long Greek name would lead us to imagine. It consists of a steel rod firmly fixed into a massive brass stand (Fig. 10). To its free end is attached a small glass bead

silvered within, so that when illuminated by a lamp a bright spot of light is thrown upon a screen placed in front of it. When the rod is set in motion the spot elongates into a brilliant line of light, whose length is regulated by the amplitude of the vibrations. A large convex lens, supported on the summit of a stand, is usually placed before the reflecting bead, so that a magnified image is depicted upon the screen, and all the effects rendered visible to a large audience at once. It is easy to improvise a cheap form of kaleidophone by firmly fixing a knitting-needle into a vice, and sticking a silvered bead upon its summit. A candle, or, still better, an Argand burner, surrounded by a shade having a slit in it, to permit the light to issue in one direction only, can be used as a source of illumination. On drawing aside the rod or knitting-needle, and liberating it, the bright line of light at first formed will be seen to change its form, gradually becoming more and more curved till it is resolved into a circle. As the vibrations slacken the changes are gone through in the reverse order, till the straight line again appears and contracts to the dimensions of the original spot, indicating that all motion has ceased. When the experiment is successfully performed, and a strong light concentrated upon the bead, the dissolving figures are of exquisite symmetry, the light playing along the surface of the screen in luminous ripples, the beauty of which cannot be adequately described, or effectively represented on paper. The various transitions from a round spot to a circle indicate the existence of movements in the rod, the nature of which could hardly have been understood before the optical method of analysis was discovered. If the movements of the rod were confined to one plane, it is obvious that its free end could describe nothing but a curve analogous to the path of a pendulum; but Wheatstone has made it evident that the rod also vibrates at right angles to the plane in which it is first set going. The result of the combined motions is the production of an ellipse, which opens out into a circle when the secondary vibrations are performing their widest excursions out of the principal plane; when the vibrations are made to succeed one another with sufficient rapidity to produce a musical sound, a sinuous curve is projected upon the screen (Fig. 11). This demonstrates the existence of partial vibrations superposed upon the primary one. The rod must therefore vibrate segmentally, exactly as a stretched string, having its nodes and consequent harmonics in addition to its fundamental tone. We can damp a rod at any point and cause a node to form, as in the case of the string, but we cannot produce the same succession of harmonics. From experiments by Professor Tyndall it appears that the first overtone of a rod fixed at one end is to the fundamental note as 25 to 4: by which ratio is meant that the first harmonic vibrates with $6\frac{1}{4}$ times the rapidity of the fundamental.

Fig. 11.—Sinuous Line described by Kaleidophone.

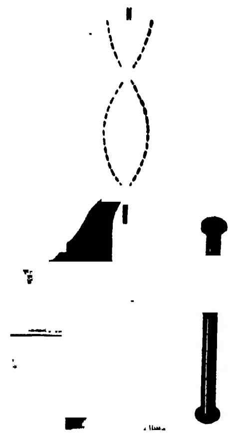


Fig. 12.—Showing vibration of Rod fixed at one end.

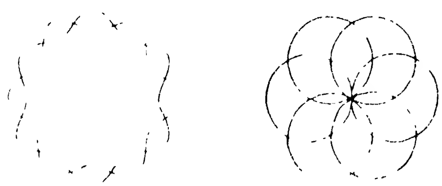
The segmental division of a rod sounding its first harmonic is shown in Fig. 12, and its appearance when projected upon a screen in Fig. 13, where we observe a spindle-shaped segment surmounted by a fan, technically termed a *semi-ventral* segment. As the rod is not fixed at its upper end, it is clear that whatever be the division of the rod, that extremity must always constitute the middle of a vibrating segment; and if it were free at both ends and held in the middle, we should have two of these fan-like semi-segments instead of one. The same thing occurs in an open organ-pipe, whose open end constitutes the widest part of a vibrating segment. The vibration of a rod free at both ends is shown in Fig. 14. It may be held or fixed at *a* and *b*, which will constitute the two nodes, and any point between the two being struck, the rod will be divided into two half segments, with a whole segment between them. Rods of both kinds are used in certain musical instruments. The reeds of the harmonium and concertina, and the metallic tongues of the musical box, are rods fixed at one end, while the strips of glass or metal employed in the harmonica are rods free at both ends. In the musical box, brass tongues of different lengths, yielding a consecutive series of notes, are placed in a row like the teeth of a comb, and their ends are

Fig. 13. Shadow thrown by Rod sounding its first Harmonic.

Fig. 14.—Shadow thrown by vibrating Rod free at both ends.

lifted by pins inserted upon a roller. The pins are so arranged on the barrel as to strike in succession the tongues emitting the desired sounds. A similar arrangement is adopted in the French street pianos, which, in London and elsewhere, have almost driven out of the field the barrel-organ, whose music did not always prove a source of unmingled satisfaction to the public at large.

In the harmonica the points to which the glass or metal strips are attached form the two nodes,



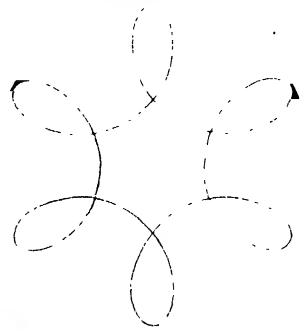


Fig. 15.—Kaleidophone Figures.

and when the hammer is applied to any point between these, the vibrations which follow take the form represented in Fig. 14. A large number of beautiful and complicated curves can be produced by the Kaleidophone, their variety depending upon the length of the rod, the place where it is struck, the smartness of the stroke, and other circumstances. A few of these figures are shown in Fig. 15. One of the most striking methods of exhibiting sonorous vibrations we owe to M. König, the distinguished acoustician of Paris. His apparatus is known as the *Flame-manometer*, and consists of two hemispherical capsules, A and B (Fig.

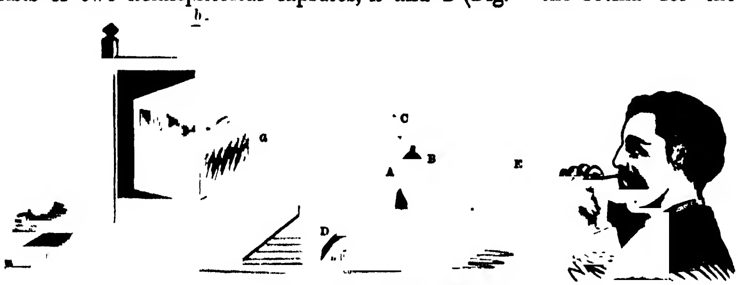


Fig. 16.—König's Manometer.

16), closely fitted together, all connection between the two being cut off by a thin elastic membrane. Into capsule A is inserted a jet or burner, C, which is fed by gas introduced into the chamber by the pipe D. Into the capsule B is inserted the acoustic tube E, which is furnished with a funnel-shaped mouth-piece for collecting and concentrating sonorous waves from any sounding body placed in front of it. Any sound transmitted through the tube will act upon the elastic diaphragm, and set it in vibration. The vibrations will be communicated to the gas in the capsule A and the jet C. When the gas is ignited the flame will synchronise with the vibrations set up in the chamber from which it is fed, and jump up and down with more or less rapidity, according to the intensity of the sound. This instrument is eminently adapted to the study of vocal sounds. We can sing or speak into the trumpet-like mouth of the *manometer*, and the sensitive flame will immediately commence its dance, in the time and motion of which we have a measure not only of intensity, but of pitch. The movements of the flame cannot readily be followed or examined by the eye alone; its image is therefore received upon a plane mirror, or piece of ordinary looking-glass, which is caused to revolve. When the apparatus is not in action, and the flame, consequently, quiescent, the effect of the revolution of the mirror is to produce a continuous band of light. It is a well-known principle in optics that visual impressions remain on the retina for the tenth of a second after the exciting cause is removed; if, then, the images of the flame are made to succeed one another at intervals of time less than the tenth of a second, they will coalesce and form a continuous luminous band. Now, if the flame is set in vibration by a musical sound the band will be broken up into a series of beautiful fiery tongues, which become more or less crowded together in proportion as the pitch of the note is raised or lowered and the rate of rotation of the mirror is varied (Fig. 17). The arrangement for exhibiting the flame images is shown in Fig. 16, where *a* is a rectangular box, having its four sides faced with looking-glass. A motion of revolution is imparted to the box by turning the handle *b*. The same effect may be produced in a much simpler way by

Fig. 17. — Flame of Manometer reflected in revolving Mirror.

attaching a string to each corner, and holding their free ends between the finger and thumb. The twisting and untwisting of the strings produce the necessary rotation. Discontinuous bands of this kind may also be observed when singing flames enclosed within tubes are examined in a similar manner; and Professor Tyndall has shown that the phenomenon is due to the rapid extinction and re-kindling of the flame. The extinction is produced by its own pulsations, and the instantaneous re-kindling is effected by the heat still left in the non-luminous gas. The dark spaces between the tongues correspond to the periods of extinction.

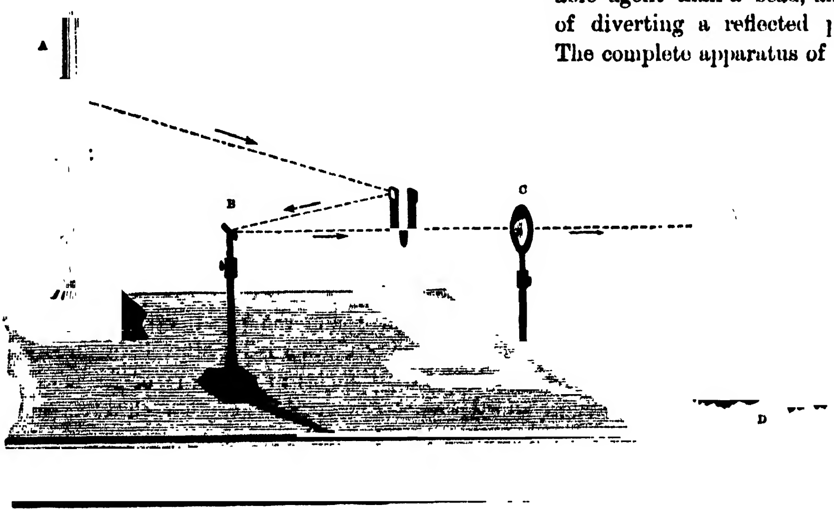


Fig. 18.—Lissajous' Apparatus for showing vibration of a single Tuning-fork.

In one of Tyndall's brilliant experiments, performed with apparatus of unusual magnitude and excellence, a large circle of these flame images was projected upon a screen by means of a concave mirror; and on bringing a syren into unison with the note emitted by the flame, and reading the number expressed on the dial, it was found that the flame had been extinguished and re-lighted 453 times in a second.

A very beautiful method of illustrating optically the vibrations of tuning-forks has been devised by M. Lissajous. Its salient feature is the attachment of a small metallic mirror to one of the prongs of the fork so as to vibrate with it. A beam of light may then be thrown upon the little mirror and reflected upon a second mirror fixed upon a stand or held in the hand, from which, by a second reflection, it may be received on a screen at several yards' distance. A straight band of light will then be depicted upon the screen, whose length will be regulated by the amplitude of the vibrations. When the tuning-fork is struck the line will be longest, because the prongs are then performing their greatest width of swing, but as the departure from equilibrium becomes less, the line shortens, and when the motion is altogether expended a motionless spot of light alone remains.

The reader will not fail to notice the parallelism between the methods adopted by Lissajous and Wheatstone for giving optical effect to sonorous vibrations. A silvered bead might be affixed to the tuning-fork, but a mirror is a much more manageable agent than a bead, and affords us the means of diverting a reflected pencil in any direction. The complete apparatus of Lissajous for exhibiting the vibrations of a single tuning-fork is represented in Fig. 18. A tuning-fork mounted on a resonant case has a small mirror attached to the extremity of one of its prongs. On the other prong there is a metal counterpoise, which is necessary to restore equilibrium and secure regularity in the vibration. It must be understood that the forks employed in these experiments are much larger than those ordinarily used by musicians, as the oscillations of forks making 256 vibrations per second are so minute, that the optical effects could not be rendered visible to a large audience. Those executing sixty-four vibrations in a second are better adapted to experiments in optical acoustics, as they are twice the size of the C tuning-forks, and emit a note two octaves below them.

A lamp (A) is surrounded by a dark chimney, in which is a small hole, allowing only a narrow pencil of light to issue. By this means the room is kept darkened, the only dispersion of light taking place in the direction of the ceiling from the orifice of the chimney. The beam of light is received upon the vibrating mirror surmounting the fork, from which it is reflected to the fixed mirror (B), and thence to any part of the screen we please. Instead of employing a second mirror,

we may view the spot of light on the screen directly by the eye itself. An achromatic lens (C), fixed upon a pedestal, is used to project a magnified image upon the screen (D). A lens of any diameter and any degree of convexity may be fitted to the stand, and its distance from the tuning-fork so adjusted as to give the necessary degree of convergence to the beam. When the fork is set in vibration the prongs alternately approach and recede, and as the little mirror is affixed to the face of one of them, the beam must be tilted alternately up and down, producing a vertical luminous line on the screen. If, while the fork is still vibrating, we partially rotate it on its axis, and thereby cause the mirror to move sideways, the straight line will become a sinuous one, in accordance with the principle already explained of the persistence of impressions upon the retina; for as we move the beam from one side of the screen to the other, its image throughout its successive displacements will remain fixed on the eye, and a wavy line is the result. By this elegant method of analysis we can represent optically the combined vibrations of two tuning-forks. We have simply to allow the reflected pencil from one fork to fall upon another similarly furnished with a mirror, and we shall get a line which will be longer or shorter than that obtained from one fork alone, in proportion as the vibrations of the two forks coincide or oppose each other, or, in other words, differ in phase. Suppose, for instance, when the two forks are agitated, the prongs of one approach, while those of the other recede from each other, it is obvious that the mirror of one fork will tilt the beam upwards, while the second mirror will tilt the reflected beam downwards; the two motions will neutralise one another, and the luminous line will be at its minimum. To express the same fact in more technical language: if the two forks pass their position of equilibrium at the same moment, but in opposite directions, the reflected image will be at its minimum, and if they pass at the same moment in the same direction, the image will be at its maximum.

The most important application of the method of Lissajous, however, is to the determination of the mechanical resultant produced by the combination of two vibratory movements acting at right angles to each other. The optical experiments illustrating these movements are not only very instructive from their physical bearing, but highly interesting in a musical sense; for M. Lissajous has shown us how to represent musical intervals by beautiful luminous figures, which undergo striking changes of curvature when the deviation from purity of tone is so minute as to be scarcely recognisable by the ear itself. Thus, two notes in unison, exhibited optically, present us with a circle; when the interval is an octave we have the figure 8, and when the notes are separated by a fifth we obtain a figure composed of three loops. To produce these marvellous results two tuning-forks are employed, as in the last experiment, but one is fixed horizontally, while the other remains in a vertical position, so that their vibrations take place at right angles. The forks vibrating independently would consequently throw upon the screen two luminous bands, at right angles to one another. By the combined action of the forks the two straight lines become converted into a curve. To render this intelligible, let us look into the philosophy of a common pendulum. If we push the bob of a pendulum out of its plane while it is swinging, it is clear that it will describe a path which will be compounded of the two motions imparted to it. The form of this new path will depend on the degree of obliquity given to the pendulum in pushing it aside and the rapidity of its oscillations. If the pendulum is impelled in a direction exactly at right angles to the plane of its motion, and the rate of its oscillations in each direction is the same, the figure described will be a circle; but if it moves twice as fast in one direction as in the other, that is to say, if the rates of vibration are as 1 : 2, the path pursued will be a double curve, each curve cutting the other at the point of equilibrium. This vibratory combination gives us the figure 8, or what geometricians call a *lemniscata*. By augmenting the difference between the rates of motion we obtain long ellipses, and an endless variety of parabolic and other curves can be produced by thus causing a pendulum to oscillate in two directions at the same moment. There are several methods by which this object may be accomplished. One of the most ingenious arrangements for giving graphic expression to the composition of motions is known as Blackburn's Pendulum (Fig. 19). It consists of a double cord, which may be attached to

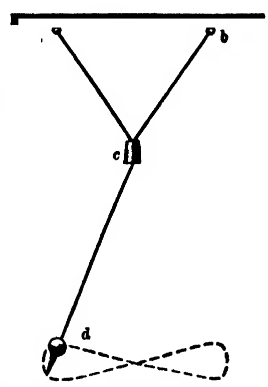


Fig. 19.—Blackburn's Pendulum.

any two fixed points, a and b (Fig. 19). Both cords are run through a sliding weight (c), and stretched by a heavy brass bob (d), below which is a style for the purpose of recording the resultant motion upon

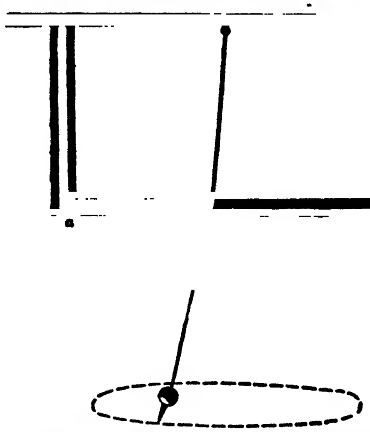


Fig. 20.—Single-cord Pendulum for tracing Compound Oscillations.

paper suitably prepared. It is evident that the portion of the cord above the weight c can only oscillate at right angles to the points of suspension, while the portion below it can oscillate independently in any direction. The resultant motion may be traced by the style upon paper strewn with sand or covered with lamp-black. Another arrangement for the purpose, still more simple, is shown in Fig. 20. In this case the cord, instead of passing through a weight, is allowed to drop between two parallel rods (a, b), about an inch asunder. These rods, of course, permit a motion in one direction only to the cord above, while that below can vibrate freely in any direction.

We are now in a better position to understand the theory of Lissajous' luminous figures. His arrangement for fixing the tuning-forks is represented in Fig. 21. In other respects the apparatus is similar to that already described. When the forks are in unison, and the vibrations are consequently as 1 : 1, the figure on the screen when fully developed will be a circle, just as in the case of our pendulum oscillating in two directions at right angles in equal times. The figure always retains the same form when the notes are in unison, no matter what the pitch of the note may be, provided that the amplitude of the vibrations is the same for both forks, and decreases in the same ratio. In performing these experiments it is not easy to cause the forks to correspond in phase, or, in other words, to start them at the same moment, in the same direction, and with the same force of percussion. The difference in phase will make itself apparent by a change of curvature in the figure, as in Fig. 22. When the notes yielded by the tuning-forks are separated by an octave we obtain the *lemniscata*, or double curve 8, as we did in the

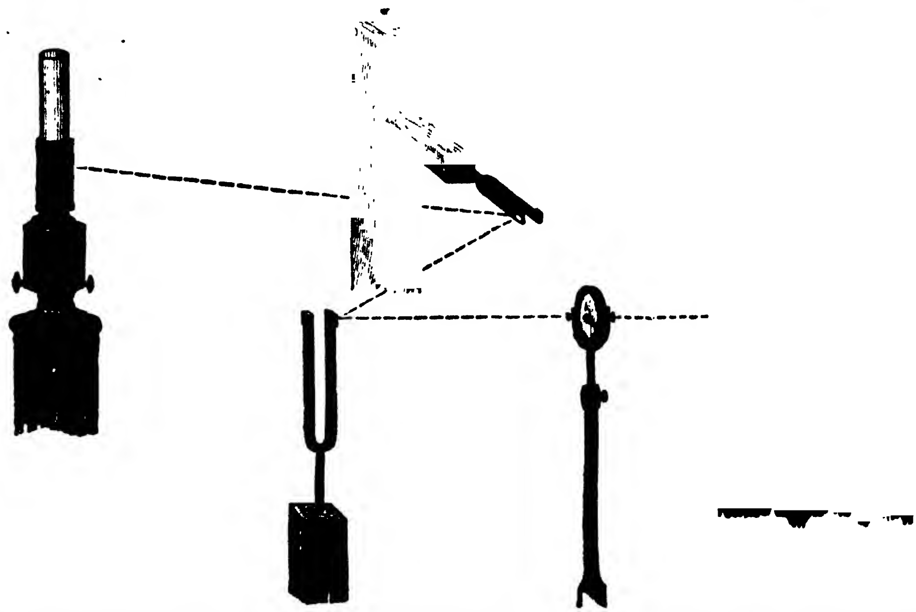


Fig. 21.—Lissajous' Apparatus for showing combined Vibrations of two Tuning-forks at right Angles to each other.

pendulum experiments when the vibrations in the two directions were as 1 : 2; for we have already learned that a tuning-fork emitting a certain note vibrates twice as fast as another sounding an octave

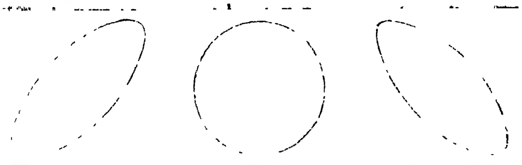


Fig. 22.—Luminous Figures produced by two Notes in unison.

below it. The difference of phase in this case is also seen by distortions of the figure upon the screen (Fig. 23). When the notes are separated

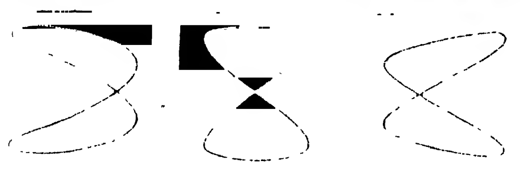


Fig. 23.—Luminous Figures produced by two Notes an Octave apart.

by a fifth, and the rates of vibration are as 2 : 3, we get the curves shown in Fig. 24. It will be noticed that they become more complicated as unison

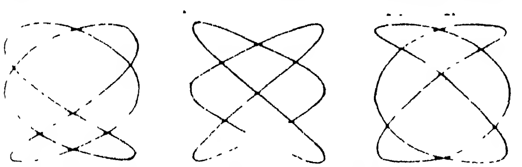


Fig. 24.—Figures produced by two Notes a fifth apart.

is departed from and the intervals become smaller; and when the interval is a second only, the luminous figures become so intricate that it is difficult to unravel the numerous convolutions which interlace across the screen. If we load one of the forks with a piece of wax or any light substance, so as slightly to lower the rate of vibration, and, consequently, throw the fork out of tune, the figure will at once become unsteady, and continue to move irregularly from side to side till the vibration altogether ceases. The method of Lissajous also furnishes us with the means of giving optical expression to the *beats* which occur when two notes nearly in unison are sounded together, and which are described in Vol. II., p. 304, of this work. The interference of the sonorous waves in this case is well exhibited in the disturbance of the luminous image, which oscillates synchronously with the beats, so that, with the figure before us, we can count their number without hearing them. When we know the number of beats we can arrive at an estimate of the extent to which the two notes depart from unison; for if six beats are heard, or optically represented, there must be a difference of six in the rates of vibration.

Suppose we employ two C tuning-forks, making each 256 vibrations per second, and by loading one of them, so as to reduce the rate to 250, we shall then observe six beats, and so on. When there are no beats the unison is known to be perfect. When an electric lamp in connection with a powerful battery is employed instead of an oil lamp, the effects are extremely brilliant, the luminous scrolls having the apparent solidity of white hot metal.

We cannot now speak in detail of singing flames, which dance to the beats. They are simply gas jets enclosed within tubes, generally of glass, and the sounds are produced by the pulsations of the air as it passes up and down the tube. Tubes of different length emit different sounds with these flames, as they do when a blast of air is simply propelled through them; and it is possible to arrange a series of singing flames sounding all the notes of the gamut, and thus to construct an organ of fire, whose music may be put out by simply turning a stopcock. There are also sensitive naked flames, or those which do not require enclosure within tubes. But the bare mention of these must for the present suffice. Enough has probably been said to indicate the extent of the comparatively new relationship which has been established between two sciences formerly dissociated. The tendency of modern scientific progress is to draw closer the bond of union between different departments of physical inquiry. Music has been brought more completely within the range of physical investigation, and what was once cultivated as an accomplishment and source of mere sensuous enjoyment is now a legitimate subject of study to the natural philosopher. The field, however, is not yet wholly explored in this direction. The famous physicists whose names we have more than once had occasion to mention, and who have made the science of sound what it is, are still at work, and we may expect that ere long acoustics will occupy a still more prominent position amongst the sciences, and that optical methods of analysis will be employed in new directions to produce novel and startling results.

THE TORPEDO.

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THE modern torpedo represents so many varied applications of science that a study of it is interesting, if only for the fact that it illustrates practically certain philosophic laws with which the student is familiar. Much relating to chemistry and physics, and particularly to electricity—induction, conductivity, electric heat, and magnetism—receives practical exemplification in torpedoes of the present day, the development of which seems to have gone hand-in-hand with the advancement of science. It is only of late years, indeed, since the invention of such explosives as gun-cotton and dynamite, and the employment of electricity in connection with these, that submarine warfare may be termed a branch of applied science. But that our readers may thoroughly understand the action of these modern weapons, it will be necessary for us, in the first place, to say something about their history.

It would be hard to say when the first torpedo, or "infernal machine," was employed in naval warfare. The awkward machines sunk by the Russians in the Baltic and Black Sea, at the time of the Crimean War, will still be fresh in the memory of many; but we may go back even to the end of the eighteenth century for examples of marine exploding weapons. Floating charges, or "petards," as they were called, seem to have been used against the British off Philadelphia about that time; and, as with some of the improved apparatus of the present day, friends appear to have been more frightened at the machines than were the foes. In a strange account of these petards, which were sent against our sailors, we are told that they were set afloat too soon, and would have drifted harmlessly away to sea, had not a boat full of British tars caught sight of the machines, and given chase, in order to capture one of the "Yankee notions." This they evidently succeeded in doing, for the end of the matter was that boat, crew, and petard suddenly disappeared at one and the same moment, and were seen no more.

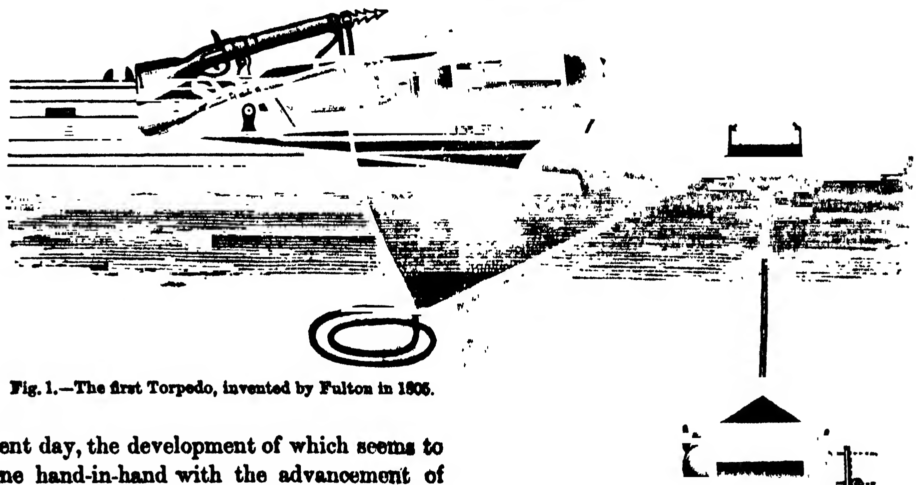


Fig. 1.—The first Torpedo, invented by Fulton in 1805.

The next step in torpedo science also emanated from America. Fulton, the well-known engineer, who was the first to navigate a steamboat, believed thoroughly in the importance of submarine fighting, and he it was who christened sunken charges by the name of "torpedo." This was about the year 1805, and it was his idea to throw a harpoon at the hostile vessel, much in the same way as a whale was at that time struck, except that Fulton anticipated modern whaling practice by employing a huge blunderbuss for the firing of the harpoon (Fig. 1). To the harpoon was attached a rope, and as soon as the former was lodged safely in the hull of the enemy, a huge torpedo, also made fast to the rope, was launched overboard. The torpedo naturally drifted towards the stricken vessel, and, on bumping against the latter, exploded. There is a letter from Fulton, still extant, in which he dwells with much emphasis on the future of the torpedo, and which, read by the light of to-day, appears almost prophetic.

After detailing the success of his steamboat voyage to Albany and back, a distance of three hundred miles, which was covered in sixty-two hours, and the advantage that was likely to accrue to his country from the use of steam as a propelling agent, he says:—"However, I will not admit that it is half so important as the torpedo system of defence and attack, for out of this will grow the liberty of the seas, an object of infinite importance to the welfare of America and every civilised country. But thousands of witnesses have now seen the steamboat in rapid movement, and they believe—but they have not seen a ship of war destroyed by a torpedo, and they do not believe. We cannot expect people in general to have a knowledge of physics, or power of mind sufficient to combine ideas, and reason from causes to effects. But in case we have war, and the enemy's ships come into our water, if the Government will give me reasonable means of action, I will convince the world that we have surer and cheaper modes of defence than they are aware of."

The Russian torpedoes planted in the Baltic may be described as the first in which chemical

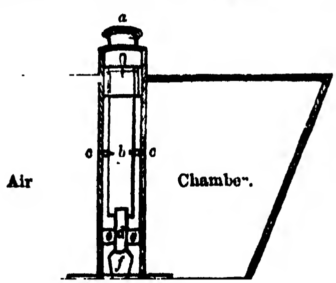


Fig. 2.—Russian Chemical Torpedo employed in the Baltic.

(a) Hammer; (b) Oscillating Cylinder swinging on Trunnions, c c; (d) Glass Tube containing Sulphuric Acid; (e e) Chamber containing Chlorate of Potash and Sugar; (f) Fine Grain Gunpowder for Primer. The Hammer when struck moves Oscillating Cylinder, which breaks Glass Tube.

science played a part. They were canisters of gunpowder, containing besides a mixture of chlorate of potash and sugar, together with a glass tube filled with sulphuric acid (Fig. 2). A ship striking a torpedo of this kind would most likely give a blow sufficient to break the glass vessel, when the sulphuric acid falling upon the potash and sugar, at once produced, by an energetic chemical reaction, heat sufficient to ignite the gunpowder. There were several objections to these torpedoes. In the first place, when they were once sunk, they were obviously as dangerous to friend as to foe; while, at the same time, to keep water out of a cylinder immersed in the sea is almost an impossibility. On gunpowder becoming damp, as everybody knows, it at once loses its virtue as an explosive; but, besides this, the Russian torpedoes were so small, that under any circumstances, there was little danger to apprehend from them.

We have made a wonderful stride in torpedo science since the days of the Russian infernal machine. Electricity is now employed as the firing agent, and explosives have been discovered which are not only more violent in their action than gunpowder, but, unlike that material, do not suffer by contact with water.*

The first instance on record of employing these modern explosives in conjunction with electricity in a system of torpedoes, was on the occasion of the defence of Venice in 1859. At that time the Austrians had possession of the city, and fearing the Italians might seek to approach it from the sea, the engineer officers entrusted with the defence of the place resolved to plant the harbour and channel with electrical torpedoes (Fig. 3). The method adopted was so simple and ingenious that we must not omit to describe it. At a prominent spot, overlooking the harbour, was built a large *camera obscura* similar to those which may be seen at many seaside resorts. This *camera obscura* reflected the "fair waters" of Venice upon a large white table, and every movement upon their placid surface was visible in the picture to those watching within. Some heavy charges of gun-cotton, which were to constitute the torpedoes, were now sunk in different parts of the harbour, each case of gun-cotton having attached to it electric wires, which led to the shore. The torpedoes were numbered consecutively, and the wires attached to them brought up into the *camera obscura*. As one charge after another was sunk, a sentinel in the *camera* watched the operation, and made a pencil mark on the camera table at the spot where the torpedo disappeared. A row boat in the harbour described a circle round the sunken torpedo, to indicate the zone of its destructiveness; and the sentinel watching this boat, made a corresponding little circle with his pencil in the picture on the *camera* table. In the end,

* See "Science for All," Vol. II., p. 328.

therefore, was to be seen in the *camera obscura* a picture, or map, of the harbour, together with a group of little circles, each numbered, to indicate where torpedoes were sunk. Moreover, at hand was a bundle of electric wires leading to the several torpedoes, which were thus placed under the control of the sentinel. His duty was to watch the approach of a hostile vessel, and so soon as he saw it get within one of the circles marked in the picture, he would proceed at once to explode the

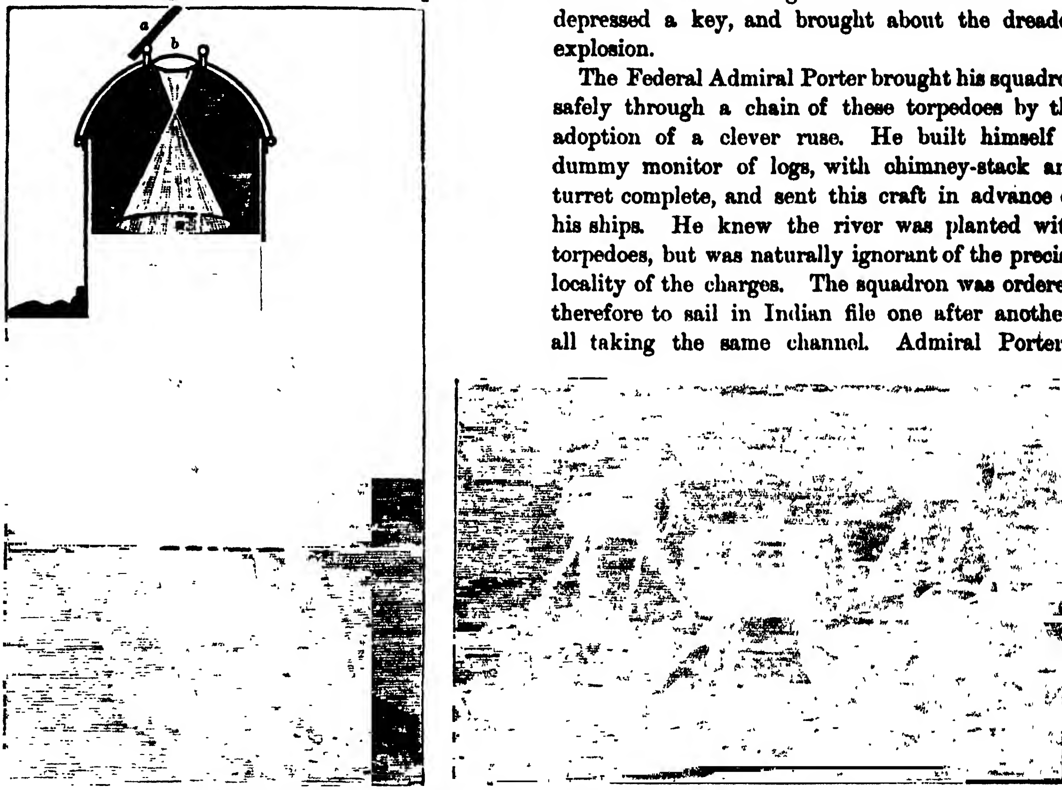


Fig. 3.—The First Gun-cotton Electric Torpedo, employed at Venice, 1859.
a, Mirror; *b*, Lens; *c*, Table upon which Camera Picture falls; *d*, *e*, Wires connected with To

particular torpedo by means of its particular electric wire.

One of the advantages of this optical system, was that the waters themselves appeared perfectly unprotected and with no sign of obstruction; but it is a method that will answer, of course, only by daylight. As soon as night comes on, the picture in the *camera obscura* is no longer visible, and the whole arrangement fails.

It was in the American war of 1861-4—Robert Fulton was certainly a prophet—that the electric torpedo was for the first time thoroughly tested and proved. During the period of that struggle, no less than twenty-five vessels of war fell a prey to the torpedo, while ten others were injured. The Confederates were particularly clever in obstructing channels and rivers with submarine mines, the vessels destroyed belonging for the most part to the Federal navy. The charges were sunk in lines, opposite certain land-marks on shore, and being connected by electric wires, could be fired at any opportune moment. A sentinel waited until the ill-fated vessel was crossing the line of torpedoes, and then with a single movement of his hand depressed a key, and brought about the dreaded explosion.

The Federal Admiral Porter brought his squadron safely through a chain of these torpedoes by the adoption of a clever ruse. He built himself a dummy monitor of logs, with chimney-stack and turret complete, and sent this craft in advance of his ships. He knew the river was planted with torpedoes, but was naturally ignorant of the precise locality of the charges. The squadron was ordered therefore to sail in Indian file one after another, all taking the same channel. Admiral Porter's expedient succeeded. As soon as the log monitor was over the chain of sunken charges, these were immediately exploded, and the craft destroyed, but the squadron following close in the wake, managed to escape without injury, and the admiral ran the gauntlet without the loss of a single war-ship.

Since that day the science of submarine mining has steadily progressed, and we have at the present moment several varieties of moored electric torpedoes. There are torpedoes ignited from shore, torpedoes which tell when they are touched by an enemy, and torpedoes which have "intelligence" enough to explode by themselves when struck. There is, too, this great advantage with an electric

torpedo. Under ordinary circumstances it is but a sunken buoy or harmless log upon the water, in which condition it remains, so long as the waters are not threatened by an enemy; but upon his approach, by the simple turning of a switch, the charges may instantly be infused with electric life, and thus formed into a barrier that is not to be passed with impunity.

The ignition of a charge by electricity is a very simple matter. Priestley and Franklin suggested the employment of electricity for firing gunpowder a hundred years ago, and submarine explosions brought about by electric agency were certainly known at the beginning of the century. The blowing up of the wreck of the Royal George at Portsmouth, was probably one of the first applications of electricity to this end, as our readers are probably aware. Before the use of an electric wire, it was no easy matter to light a charge under water. It was usually done by leading up a metal tube from the gunpowder below, to the surface of the water, and then dropping down this channel a ladleful of red-hot shot or heated fragments of iron. The latter not unfrequently cooled in their descent down the tube, and for this reason often failed to effect their purpose, while the vicinity of the operators to the explosion was another not less serious drawback. With a wire and an electric battery at one's disposal, there is not much difficulty in igniting a charge of gunpowder or other explosive. It is usually done with a wire-fuse attached to the end of the conducting wire, the fuze being inserted inside the charge. This wire-fuze may be said to consist of a cut wire, the ends joined together again by a bridge of platinum thread. Its object is to convert the electric fluid into heat, and this is done by offering an opposition to the passing current. The wire from the shore to the torpedo is of copper, which is a famous conductor of electricity; and so long, therefore, as the current passes along the copper, no rise in temperature is noted. But platinum, unlike copper, offers very great resistance to the passage of electricity, and the consequence is, that, as the current goes over the little bridge of fine platinum wire, this is heated to redness. Supposing the red-hot platinum to be in contact with gunpowder or gun-cotton at the time, there will naturally enough be an explosion; and this explosion may therefore be brought about at any time that you choose to send a current of electricity along the wire connecting the torpedo with the shore (Fig. 4).

The wire-fuze is found to be better still, if instead of platinum, an alloy of platinum and iridium is employed for the tiny bridge. It is the simplest method of applying electricity to the firing of charges, but there are other fuzes not less efficient. There is the Abel fuze and the Beardslee fuze, for instance (Fig. 4). The latter consists simply of a bit of wood, into which the ends of two wires are thrust; one surface of the wood, that at which the two wire heads appear, is perfectly smooth, and instead of connect-

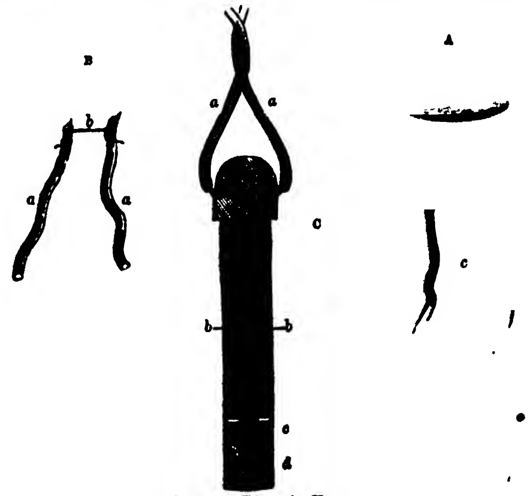


Fig. 4.—Electric Fuzes.

(A) Head of Beardslee fuze:—aa, Heads of Electric Wires; b, Pencil-mark between Wires; c, Wires leading to Battery. (B) Simple wire-fuse:—aa, Copper Conducting Wires, b, Fine Platinum Wire, heated by Electric Current (C) Abel fuze:—aa, Electric Conducting Wires; bb, Wires in Fuze; c, Phosphide of Copper Composition into which the heads of Wires dip; d, Gunpowder

ing the wires together with a platinum bridge, the operator simply draws a line between them with a black-lead pencil. The pencil-mark consists of tiny particles of graphite, and the electric current or spark passing between the wires, raises the particles to a high temperature. The graphite thus heated by the resistance it offers to the electric current ignites a sensitive compound in the neighbourhood, and thus fires the torpedo. In the Abel fuze, a more delicate substance—a phosphide of copper composition—is employed at the poles or heads of the wires to generate heat and bring about explosion.

Thus, in an electric torpedo, when once our fuze is fitted therein, we have simply to take care that an electric current shall arrive at an opportune moment to explode it. But this electric current must be of a certain nature, or it will fail to do its duty. The Abel fuze or Beardslee fuze, which is fired, so to speak, with a spark, requires a different kind of electricity for its action from that necessary for the wire fuze. In the former case, we must have recourse to "high tension" electricity; in the latter, to "low tension." A voltaic battery

evolves "low tension" electricity, and is suitable for the wire fuze, but a battery made up of metal plates, and involving the use of acids, is an awkward apparatus to carry about and employ as a warlike implement; this is why our military and naval men hesitated for some time to bring the wire fuze into general use. Colonel Verdu, a Spanish officer, seems to have been the first to endeavour to do without the wire fuze, and he made many experiments with a view to ascertain whether gunpowder could not be ignited by a spark, or "high tension" electricity. With a Ruhmkorff coil, Colonel Verdu succeeded so far as to fire several charges simultaneously in this way, but it was not until the late Sir Charles Wheatstone and Professor Abel joined hands in an investigation of the subject that it was brought to a practical head. Mr. Abel, as we have said, devised a "high tension" fuze, and Wheatstone constructed a portable magneto-electric machine for firing the same.

One of the first electric firing machines made for warlike purposes was for the China war in 1860. This was a very clumsy affair. In shape and size the apparatus looked like a baker's barrow, which contained a monster horse-shoe magnet; a big armature was attached to the magnet, and the sudden separation of armature from magnet gave rise to a current sufficient to fire an Abel fuze. Shortly

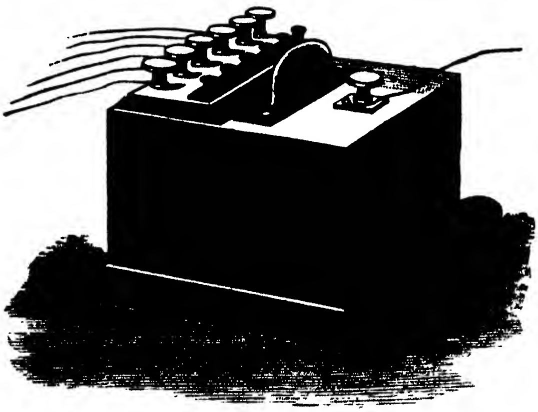


Fig. 5.—Wheatstone Exploder.

afterwards this monster barrow gave place to a neat mahogany box measuring about twelve inches across, which contained half a dozen powerful magnets, in the field of which the armatures were made to revolve (Fig. 5). By turning a handle swiftly enough energy was generated from this Wheatstone exploder to fire twenty charges at a time, the wires branching off in all directions from the instrument. Since then further progress has been made, and we are now in possession of magneto-electric machines, termed dynamo instruments, capable of evolving low tension electricity, and therefore fit to fire wire fuzes; it is for this reason that the latter have once more come into favour with our military and naval authorities.

Perhaps the best proof we have of the defensive power of electric torpedoes was afforded at the time of the Franco-German war of 1870, when the *French fleets, only second in might to our own*, were kept at bay by the well-constructed submarine defences of the Germans. So rigidly was the coast of the Fatherland guarded, that the French ships of war hardly ventured within sight of shore during the whole period of the struggle. A knowledge of chemistry and physics, or, in other words, modern explosives and the science of electricity, combined to paralyse the whole of the French navy, and allowed the Germans to concentrate their energies upon their army. Dynamite was the substance chiefly employed in the German torpedoes, and they were for the most part chiefly arranged so as to be exploded at will from the shore. But besides these, the Germans devised two kinds of self-acting electric torpedoes. The first was fired by means of a circuit-closer arrangement (Fig. 6). The torpedo-charge contained an electric fuze, as usual, of which one pole, or wire head, was connected with a battery on shore; the other pole of the fuze was connected with an insulated plate at the head of the torpedo. Over the top of the torpedo was spread an iron cage or guard, something of the form of an open umbrella, supported on a central pivot, and this umbrella, on being struck by a ship or other floating object, swerved bodily round, a movement that brought it into metallic contact with the insulated plate we have mentioned. In this way the insulation was for the moment removed, and the current from the electric battery passed unimpeded through the fuze, when explosion, of course, immediately followed; for, as we know very well, no current can pass unless the electricity has free circuit. The principle of the torpedo was therefore to have the circuit incomplete, in which condition it remained until touched by a passing vessel; a blow on the guard completed, or closed, the circuit, and then the current being no longer impeded, fired the fuze. In the other torpedo, known by the name of the Herz torpedo, the electric battery, as well as the fuze, was contained in the submarine mine itself. The battery inside the torpedo was, however, dry, and therefore impotent under ordinary circumstances; but as

soon as it was struck by a passing vessel, liquid rushed into the battery, which, being thus set into action, was capable of exploding an electric fuze.

Another form of electrical torpedo is that by means of which the Turkish monitor was blown up on the Matchin canal. The charge in this case, about 50 lbs., is borne at the end of a long pole, which projects from the bow of a swift torpedo launch. The launch is run full tilt at its victim, and as soon as the charge touches the enemy, it is exploded by means of a fuze in the manner we have previously indicated. The employment of torpedoes in this fashion is fraught with considerable danger not only from the enemy, but from the explosion of your own torpedo, which, if not skilfully manipulated, is just as likely to work the destruction of the launch as that of the hostile vessel.

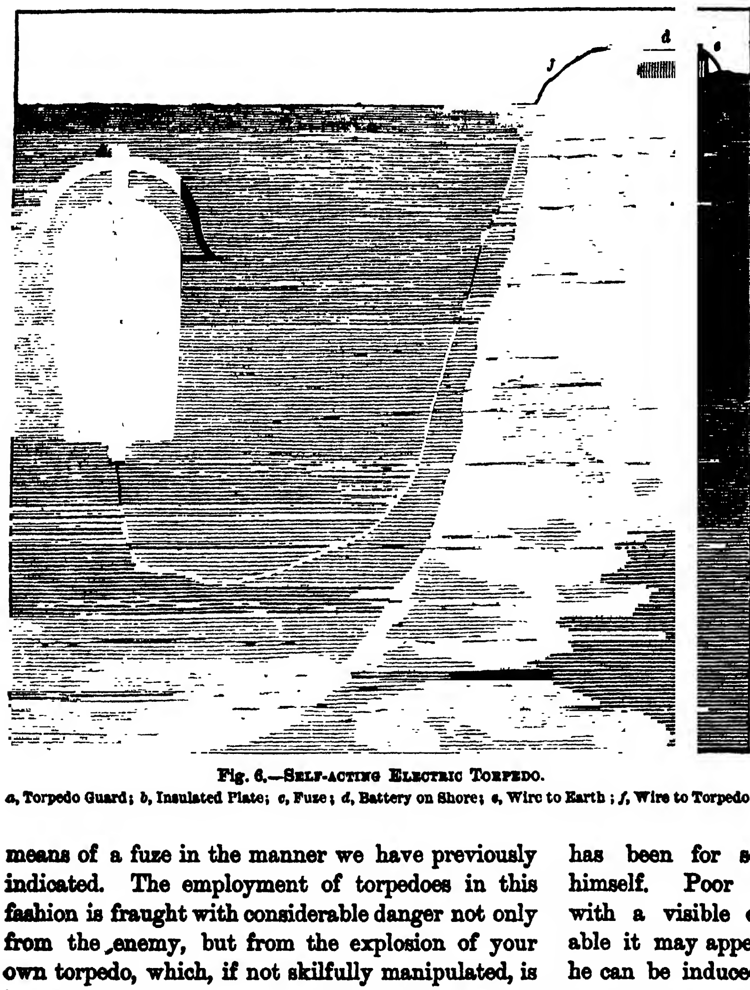


Fig. 6.—Self-acting Electric Torpedo.
a, Torpedo Guard; b, Insulated Plate; c, Fuze; d, Battery on Shore; e, Wire to Earth; f, Wire to Torpedo.

Gun-cotton and dynamite, we have said, are far better adapted for submarine explosions than gunpowder, not only because they do not suffer from contact by water, but because their action is four or five times more terrible than that of the older explosive. A moored torpedo containing 500 lbs. of gun-cotton or dynamite will blow in the bottom of an ironclad, if the latter happens to be within forty feet of the charge; or, in other words, a cushion of water forty feet thick is insufficient to defend an ironclad from injury. But terrible as they are, the new explosives are endowed with a weakness that is not shared by gunpowder. The latter, speaking generally, can be exploded only by spark or flame; the new explosives may be detonated by vibration. If you have a long tube with a charge of gun-cotton at either end of it, and detonate one of the charges, the vibration transmitted through the tube will explode the second charge. If you place the two charges near one another in water, you do not want a tube, the water itself serving to carry the vibration, and in exploding one of the charges the other will follow suit as a matter of course. This curious fact has been eagerly seized upon by our naval officers, and by its means we have elaborated an efficient system of defending ourselves from torpedoes, termed countermining.

We have hitherto spoken of torpedo warfare from an offensive standpoint; countermining permits us in a certain measure to annul the terrible effect of modern torpedoes. It is well such is the case. Torpedoes charged with dynamite or gun-cotton, and endowed with electric life, are the most deadly of weapons, and of a kind, moreover, against which the sailor has been for some time powerless to defend himself. Poor Jack does not mind coping with a visible enemy, no matter how formidable it may appear; but it is rare indeed that he can be induced to enter a channel or harbour where he expects to be blown up every moment. It is gratifying to learn, therefore, that science is just as ready to stand his friend as his enemy, and is able to provide him with a means of defending himself against the lurking torpedo.

To the Danish navy belongs the credit of having initiated the science of countermining. In instituting a series of experiments with dynamite submarine mines, it was found that the vibration caused by the

explosion of one charge sufficed to bring about the ignition of those in the neighbourhood. A torpedo containing 150 lbs. of dynamite sunk in ten feet of water exploded a second charge of the same kind at a distance of 300 feet. That is to say, the sea-water conveyed the vibration a distance of 300 feet, and at the end of that journey the disturbance of the water molecules was still so great as to bring about the explosion of another torpedo. In exploding a lighter charge, the vibration does not travel so far, while in the case of heavier charges the disturbance of the water will naturally travel a longer distance. The depth at which the charges are ignited has, as a matter of course, also an influence on the result; but, by experiment, it has been possible to draw up a table of distances which answer for all practical purposes, and with these data to go upon, the operation of countermining is not a very difficult one.

It is quickly explained. A captain desires to approach a hostile coast planted with torpedoes. If he touches any of these he will most assuredly be blown into the air, and his object is therefore to explode them with impunity to his ship and crew. He knows that if he himself ignites a heavy charge of dynamite under water, the vibration caused by the shock will have the effect of exploding all other similar charges within a radius of 300 feet, the sea being the medium whereby the vibration is transmitted on all sides. This, therefore, he proceeds to do. He has a steam-launch hung around with countermining charges, and this goes on before to clear the way. At an interval of, say, every 250 feet, a countermine is sunk and exploded, and in this manner the captain is enabled to make his way slowly but surely. But is not this operation of countermining a service of some danger? it may be asked; and would not those on board the steam-launch run considerable risk both from the enemy's charges and their own? Most certainly; if there happened to be anybody on board the countermining craft he would be in a very dangerous position; but there is no need fortunately for any such risk. Electricity once more comes to our aid, and by its means we are enabled to guide and steer our launch, without putting a single man on board of her. The launch is connected by electric wires to the vessel in her wake, and from the latter the launch may be steered without difficulty. In firing the torpedo, as we have shown, we employ a magneto-electric machine converting magnetism into electricity, but for steering the countermine launch, we employ electricity to generate magnetism. In the launch, the two ropes controlling the rudder are coiled round two movable metal drums, and so long as these drums are free to revolve, the rudder-ropes remain loose, and the launch proceeds in a straight line. Either of the metal drums, the one on the right or the one on the left, may, however, be at any moment held fast and prevented from revolving by a powerful electro-magnet; and when one drum is so fixed the rope coiled thereon will be checked, and the rudder in this way turned for a long or short time, according to the duration of the electric current. The electro-magnets in the launch are connected by electric wires to the vessel following, so that any one having control over the wires can steer the launch how and where he pleases from the deck of the war vessel behind. In like manner electric wires lead to the engine-room of the launch to control the engines, which are stopped and set going by electric agency without difficulty. The Americans have devised several self-steering launches of this character.

But electricity, useful as we have shown it to be in torpedo science, is endowed, like our modern explosives, with a failing that sometimes plays sad havoc among submarine mines. What our readers know by the name of "induction," is a source of considerable weakness occasionally in torpedo defence. An insulated body charged with electricity, brought into the neighbourhood of another insulated body, causes the latter to be charged with electricity also. Now, in the case of the insulated wires leading to torpedoes we have bodies that are capable of being charged by induction, and hence it follows that explosions are liable to occur from this cause. When high tension fuzes are employed, the tendency to explosion by induction is, according to German authorities, much greater than when wire fuzes are used, while, again, electricity from a frictional machine (whether of ebonite or glass) is peculiarly liable to set up induced currents in neighbouring wires, and thus to explode other torpedoes beyond that whose ignition it is desired to bring about. Electricity in the atmosphere will also induce electricity in sunken torpedo-wires, and thus cause accidental explosions, although we are bound to say that such things are of rare occurrence.

In conclusion, we ought perhaps to say a word about the Whitehead or Fish-torpedo, which has attracted a great deal of attention. The "fish" is a purely mechanical instrument, but so ingeniously constructed that it appears to be endowed almost with human intelligence. Indeed, it has been said of this class of torpedo, that it can do well-nigh

everything but talk. The fish is a cigar-shaped tube, some dozen feet in length, and divided into three portions. Its head contains the explosive —gun-cotton or dynamite—with which it attacks the foe, the charge detonating as soon as the nose of the torpedo strikes an obstruction. The centre of the machine consists of a stout reservoir, in which atmospheric air is compressed to the extent of 600lbs. on the square inch, so that an elastic force is here stored up which serves as the motive power for the torpedo. Behind the reservoir is the machinery of the torpedo, set in motion by the compressed air escaping from the reservoir. The fish is so contrived that it will swim at any desired depth, but is usually made sufficiently buoyant to float about eight feet from the surface. It proceeds in a perfectly straight line, if unaffected by tide or current, and is aimed from a tube much in the same way as a rocket. When properly charged—an exceedingly powerful air-pump is necessary for the purpose—the fish will do a journey of a mile and a half under water, the first 1,000 yards being got over at the rate of twenty miles an hour.

TASTE.

By F. Jeffrey Bell, B.A., F.R.M.S.,

Professor of Comparative Anatomy in King's College, London, etc.

In a previous article* we dealt with Touch, which is, perhaps, the most generalised of all the senses; we now propose to deal briefly with the phenomena which are associated with tho sense of Taste. We shall first direct attention to the functions of the gustatory organs as exhibited in ourselves, for these are the most interesting to all of us; and, inasmuch as we know most about them, this is the easiest way of commencing an essay on the subject. At the same time, it is right and necessary to call attention to the fact that the discussion of sensation-experiences is one of the most difficult of the many difficult questions with which the physiologist has to do.

As before, let us commence with a few anatomical considerations:—The chief, though not the sole region with which are connected the special end-organs † of the sense of taste, is that muscular organ, the tongue, which is of so great assistance to us in masticating our food, and in giving utterance to our thoughts. On the surface of this tongue there are to be distinguished a number of more or less minute projections, which are known generally as *papillæ*. Of these some are comparatively large (Fig. 1, *cv*), and are surrounded by a wall of the soft mucous layer which invests the muscular body of the tongue: it is in consequence of this arrangement they are called *circumvallate papillæ*. Others, which are smaller, and form a rounded cap at the upper extremity of their narrower stalks

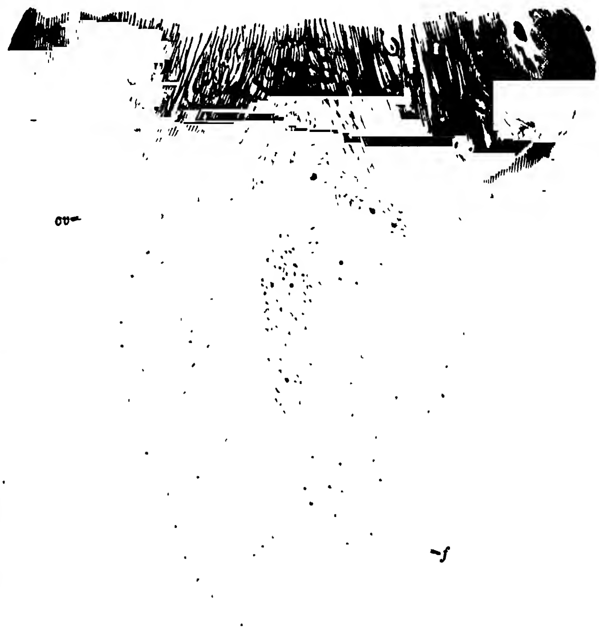


Fig. 1.—Figure of the Upper Surface of the Tongue. (*cv*), Circumvallate Papillæ; (*f*), Fungiform Papillæ.

(whence they are called *fungiform*) are more numerous than the circumvallate papillæ, of which there are not more than twelve (and rarely so many) on the human tongue. There still remains a third set of yet smaller processes, which are so

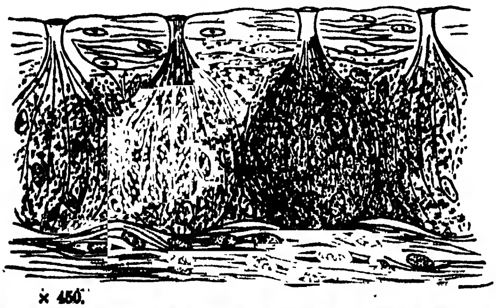
* "Science for All," Vol. II., p. 304.

† It was pointed out in the article on Touch, that "end-organs" were necessary for the appreciation of what happens outside ourselves.

delicate as to have received the name of thread-like, or *filiform* papillæ.

The papillæ consist essentially of a layer of flattened "epithelial" cells investing a mass of "connective" tissue, and containing in their midst a number of bulb-like bodies, which appear to be the proper end-organs of the nerves of taste (or gustatory nerves); these bulb-like, or flask-shaped bodies open on the surface of this "epithelium" by a circular gustatory pore, which forms, as it were, the orifice of the neck of the flask (Fig. 2). If we

A



× 450.

B

× 25

Fig. 2.—(A), Taste Bulbs of the Rabbit; (B), Transverse Section through Taste-folds of the Rabbit. (*After Engelmann.*)

compare what obtains in a number of animals, we find that the taste-bulbs vary considerably in their more intimate characters; but it is not necessary for us to enter into the details of the arrangement of their several parts. It is sufficient to know that they are chiefly found around the sides of the circumvallate papillæ, though they are also to be found upon the fungiform processes. In their essential characters they are thus constituted; they

Fig. 3.—Gustatory Cells.
(a), Separate Cells; (b), a Taste-cell with Covering Cells.

are made up of two different kinds of cells,—of these the outer or covering cells are elongated bodies filled with a clear protoplasm, which are not connected with nerve-branches; they are of pretty much the same breadth throughout, exhibiting only considerable diminution of size at those points at which they approach the neighbourhood of the above-mentioned gustatory pore; the inner cells, which are technically known as *gustatory*, are long and thin, and have a broader outer and a much more delicate inner process (Fig. 3). On the circumvallate papillæ, they are to be found only in those portions which are guarded by the fold of mucous membrane which forms, as it were, a rampart around them; on the fungiform papillæ they are more sparsely distributed, and from these the filiform papillæ are to be distinguished by the presence of a number of more or less stiff hairs which, taking the place of the covering of specially modified epithelium found on the other papillæ, seem to afford to them the power of assisting in the mastication of the food, just as much as (if not, indeed, much more than) in detecting the sensations of taste which the food, taken into the mouth, excites.

Let us turn now to the second agents in sensation, to the nerve-branches which are especially connected with the taste-bulbs; these we will discuss before we pass on to consider the somewhat more difficult question as to the special nerves by which these branches are connected with the brain; or, in other words, with that reasoning organ * which aids us in forming our judgment, and keeps a register of the sensations experienced in the past. Fine nerve branches, aided by rounded, cell-like "ganglia," pass off from the larger nerve-trunks into each papilla; breaking up, and forming a meshwork, or "plexus," beneath it, the connecting strands of nerve fibre then pass on into it, and make their way towards the surface; careful as the observations have been on the part of those who have examined into this subject, with the most elaborate assistance that modern methods of microscopic research afford, they have not yet been able to make out in all their details the relations which subsist between the more delicate nerve-fibrils and the gustatory cells.

When we come to the question as to what is the *proper* nerve of taste, we find it necessary to make a few observations on a subject which has not yet been treated of in this serial; from that great mass of nervous and other tissue which, in man, constitutes the brain, there are ordinarily said to be given off, on each side, twelve distinct nerves; some of these nerves are specially set apart for the purpose of

* "Science for All," Vol. II., p. 307.

acting on the muscles of the face, or on the muscles that move the eye-ball, others give to the brain indication of what is affecting the skin of the face, and others send some fibres to organs as far away from the brain as the heart, the lungs, and the stomach. Now, all those great nerves which arise from the spinal cord give off two branches, one of which has the duty of conveying to the spinal cord and so to the brain, the results of affections of the end-organs —and these are *sensory* nerves; others have for their function to convey what may well be called messages from the brain to the different muscles of the body, and these are the *motor* nerves. When we examine those branches which are given off directly from some part of the brain itself, we find that the great majority have only one function; the "first" supplies the organ of smell, and is an *olfactory* nerve, the second supplies the end-organs of the *retina* (where are placed the special bodies by which we primarily get our sensations of light and colour); the third, fourth, and sixth pairs are *motor* nerves only, and go to the muscles which move the eye-ball; while the eighth, in the same way, supplies the ears and is the *auditory* nerve. Leaving aside the rest, with the exception of the fifth, let us consider in a little more detail, its more especial characters (Fig. 4). Sir Charles Bell, to whom we owe the foundations of our knowledge of the difference between sensory and motor nerves, admirably expressed its function when he spoke of it as being the "spinal nerve of the brain." This fifth nerve has, in fine, two branches, one sensory and one motor, as the just-mentioned physiologist was the first to demonstrate. In addition to this, the larger branch, which is the sensory division, has, just like the sensory roots of the spinal nerves, a *ganglion* near its root; it is this upper portion which supplies the tactile organs of the optic region and of the face, of a considerable portion of the mucous membrane which lines the mouth and the regions lying beyond, as well as of the tongue. To this latter organ it also sends branches for the supply of the special end-organs of taste; but this is not all that it does, it supplies further, by its lower or *motor* * half, the muscles which act in mastication, so that in addition to being the nerve for tactile and for gustatory sensations it is also important as assisting us very largely in manducation. Long thought to be the sole nerve of taste, it is now known to supply all the parts of the tongue nearest the tip, while another cerebral nerve (the ninth of those that arise from some region of the brain) in addition to its other duties, supplies the hinder region of that organ.

* In connection with this subject, see "Science for All," Vol. I., pp. 174—180.

Putting aside the important lessons which may be derived from the distribution just now very briefly described, we may learn, with regard to the subject that we have more particularly in hand, that the sense of taste is to be distinguished from the other three senses—those of smelling, seeing, and hearing—with the organs for which cerebral nerves are connected, by the fact that it has no special nerve appropriated for its use only. In other words, we cannot speak of a nerve of taste

Fig. 4.—Fifth Pair of Nerves.

in the same way as we can speak of an optic or an auditory nerve.

It will be unnecessary for us to enter into any account of the general distribution of the ninth or "glosso-pharyngeal" nerve. Its name, indeed, will indicate this sufficiently enough to those who know that "glôssa" is the Greek for tongue, and that the pharynx is the hinder portion of the cavity of the mouth; it will be sufficient to repeat that the branches from it which supply the taste-organs of the tongue are sent only to the more posterior portions.

When we come to analyse the sense of taste, we find another kind of difficulty in our way; this sense of taste is so closely associated with that of smell, that it is, at times, difficult for us to be able to discriminate between the effects of these two sensations. We have all seen the refined gourmand who smells the wine on which we ask his opinion,

and we all know, to our comfort, that the more disagreeably-tasting drugs, which are imposed on us as a punishment for our own imprudence, are less nasty when we take them for a "cold in the head" than they are at any other time. Howsoever, it is possible to distinguish four sets; there is the bitter, the acid, the sweet, and the salt; and, as Professor Schiff has pointed out, these are probably the only proper names to apply to what are truly sapid substances. The just-named physiologist, who has so greatly distinguished himself by his numerous researches into the various physiological processes of digestion, has demonstrated that what we call the taste of "oily" bodies is really a compound sensation due to the sense of a diminution in the friction between the tongue and the soft palate, combined with a perception of the specific odour of the fatty body. In support of this proposition, he points out that those happy individuals that are unable to *smell* castor-oil, are also unable to taste it, while he directs attention to the experiments of Dr. Romberg, which have shown that in patients affected by the loss of the sense of smell or who possess it in a diminished degree, there is no sense of taste for any bodies which are not purely bitter, acid, sweet, or salt; taking two simple examples, he states that he imagines that the difference in the taste of the almond and the chestnut is largely due to the difference of their odour, which, as we may fairly suppose, is dependent on the difference in their essential oils. Sufficient has been said to show that the sense of taste and the sense of smell are, in their essence, independent, but the relations which exist between them are, except for the more markedly sapid bodies, so intimate, that it may, perhaps, be as well to add another proof. The point on which we desire to insist is, that the sense-organs of taste are really capable of exercising their function without any assistance from the sense-organs of smell, and we dwell upon this, notwithstanding the fact that very commonly a sapid body sends messages to the brain by means of both sets of organs, because we desire to draw especial attention to the proper characters of the terminal organs of the special senses. A conclusive case in point is ready to our hand in the observations made more than a quarter of a century ago by an American physician. Dr. Hutchinson observed, that in a negro in whom the sense of smell was altogether lost, sapid inodorous substances were felt by the organ of taste in quite the ordinary manner; and this observation seems to be, of itself, a complete demonstration of the special value of the end-organs, on which we must not be thought to be insisting too much.

The careful observations of certain foreign physiologists seem to enable us to give a pretty definite account of the regions of the tongue, which are concerned in the sense of taste. The tip appears to be excited only on its under surface; the upper surface is distinctly sensory in the posterior third only, and the edge is provided with a narrow band to which the proper sense-organs of taste are confined. The tongue, however, is not the only region supplied by the gustatory branches of the glosso-pharyngeal nerve; and it is found that the hinder part of that portion of the roof of the mouth, which is known as the "hard palate," together with the adjoining region of the "soft palate," and the anterior pair of descending prominences connected with this latter ("anterior pillars of the fauces"), are also capable of being excited by sapid substances. Our knowledge of the phenomena of gustatory sensations is still very far from being complete; but this is, perhaps, largely due to a cause which, it is to be feared, can never be overcome,—namely, that sapid bodies to be tasted must be soluble, and soluble bodies become largely spread over the whole area of the mouth's cavity. There have, however, been sufficient observations made to justify, to a great extent, the dogmatic assertion that sweet substances are most easily recognised at the tip of the tongue, acid at the edge, and bitter at the back. The remarkable results have been attained by the use of an electric current, as shall now be explained. When we take in one hand one end of a wire connected with a galvanic battery,* and apply the other end ("pole") to the tongue, the sensation of taste is excited. When the so-called positive pole is placed on the tongue, we feel an acid taste; and if the negative is placed on it, we feel the same sensation as is produced by an alkaline body. This observation was, in earlier times, explained by regarding the effect as due to a decomposition by the electric current of the salts contained in the saliva; but it is now more reasonably supposed to be due to the influence of the electric current on the nerves of taste. Temperatures considerably lower than that of the body, or much higher, diminish or destroy the sense of taste; and the common fashion of adding ice, in these days of cheap wines, may, from a physiological point of view, be not unfairly regarded as due to an unconscious knowledge of this physiological fact.

* "Science for All," Vol. I., p. 46, and Vol. III., p. 51.

We have now attempted to direct attention to the more prominent facts connected with the sense of taste; as to that peculiarly disagreeable sensation of a long-continued taste in the mouth, nothing of value can be as yet suggested. And it now only remains for us to say a very few words about the gustatory organs of other animals than man. Little is definitely known as to the structure of the taste-bodies in the insects, although our ordinary observations are sufficient to show us that this sense must be very far from feebly developed in this highly organised group. A German observer has lately described certain goblet-shaped organs which he has found scattered over the more anterior regions of certain marine annelids (worms); and to these, although they are not confined to the cavity of the mouth, he seems well justified in ascribing a gustatory function. In connection with this, it is of considerable interest to point out that there are developed on the lower backboned animals, though more especially in fishes, goblet-shaped organs, which are set in various parts of the skin, and which, in the general opinion of all anatomists, have some higher function than that of mere touch organs. The delicate thread-shaped papillæ of the human tongue are specially modified in some of our more immediate zoological allies. They are considerably increased in size in the dog, who uses them to lick his bones; and in the lion, they are of such considerable power, that, as Dr. Carpenter remarks, he, "by a single stroke of his tongue, can take off the skin from any part of the human body."

THE EYE AND ITS USE.

By William Ackroyd, F.I.C.

It is easy to work with an instrument without knowing anything at all about its construction. Thousands of tourists yearly point their "glasses" to mountain and mere without having the least idea in what manner their wonderful instruments bring that which is afar off comparatively near to them; and how many millions are there who use their eyes every waking hour of their lives without knowing anything about the build of these wonderful organs! Yet, if one sets about it properly, it is very easy to learn quite enough to understand how the eye is built up, how its parts work harmoniously together, and how we have acquired our ideas of form, size, distance, &c.

If desirous of knowing all about the telescope, our first work would be to take it to pieces, and then we should try and ascertain as well as we could the use of each part, arriving finally at a conception of the working of the whole instrument. We must proceed similarly in the case of the eye. Let us, then, dismember an eye, and by a series of intelligent observations, experiments, and comparisons we may arrive at all we at present want to know—the structure and use of it. Fortunately for our purpose the eye of a sheep or cow will do quite well. If you send to the butcher for a couple, he will probably, as in my case, send you half a dozen. With these make the following investigation. Take one and cut off the muscle which has been left adhering to the side. Now note that the eye-ball is nearly spherical, and has a white cord projecting from the back. This cord proceeds into the interior of the eye, and before it was severed, connected the eye with the brain. Without cutting up the eye we can ascertain little more now than we do by an inspection of our own eyes in the looking-glass. We observe a transparent, circular front, which bulges out slightly; this is the cornea, and it merges into the "white of the eye" or *sclerotic coat*, which seems to form the rest of the eye-ball. Under the transparent cornea one sees a coloured ring, the iris, and the opening in the middle of this is termed the pupil. We may turn now to make a cursory examination of its interior. With a pretty sharp razor cautiously make a cross incision into the cornea of the cow's eye. As soon as the thick cornea has been cut through, a watery-looking fluid issues, which is termed the *aqueous humour*. When the incision has been made large enough, gently press the eye-ball, and there will be squeezed out a most important organ, the *crystalline lens*, truly crystalline, for it is *ice-like* in its transparency and purity. It is not always thus, for on the approach of old age it becomes tinged with yellow, and has then a peculiar effect on the colour sense, not of much consequence save in the case of an artist. To one troubled with this defect, the *strong* blues presented by nature in daylight appear bluer than they are, and the *weak* blues of his pigments much weaker than they are. But in following his art

the painter has to copy nature's bright blues, with the weak blues he has before him in his pigments, and consequently puts too much of the latter on to his canvas in his endeavour to represent nature faithfully. This was Mulready's condition in his old days, and Leibreich points out that his later pictures are too cold, and only look of a natural tint when we observe them through yellow glass. After observing well the form of the lens, how that it is more convex on one side than on the other, put it on one side for future experimental use. One of the incisions that have been made in the cornea may now be enlarged, so that the sclerotic coat is cut through and the eye-ball nearly bisected. The remainder of the eye-ball will be found to contain a perfectly colourless and jelly-like substance, the *vitreous humour*. Through this transparent humour the colour of the internal coating of the eye is plainly visible, of a satiny, and in some parts a perfectly violet tint. The wall or spherical shell which surrounds the vitreous humour consists of three layers—the inner coloured one, termed the retina, the outer sclerotic coat, and between these two the choroid coat, which is lined with pigment on the side which it presents to the retina. The more minute structure of some of these we must inquire into farther on, and now before the mangled eye is pitched away, note the spot on the retina where the white cord or optic nerve enters, by pushing a pin through the nerve into the interior. The pin-point will be found to come out a little to one side of the central portion of the retina.

Our preliminary work has necessarily been of a rough nature; we have been settling broad landmarks, and the reader who may be inclined to go in for a more minute survey will now use the microscope and dissecting apparatus, and have recourse to the instructions furnished by special works of too technical a nature to be detailed in these pages. We have done well if the position and shape of the principal parts are understood, so that we can form a picture in the mind's eye of the inside as well as the outside of the visual organ. To aid us in this, let us turn to a finished diagram, so that we may understand one or two points concerning which we are at present a little hazy—as, *e.g.*, the exact position and mode of suspension of the lens, how the iris is attached, &c. &c.

On reference to Fig. 1, it will be seen that the lens is placed between the vitreous humour and the aqueous humour, and is kept in its place by a membranous frame, which extends from the edges of the lens to what are termed the ciliary processes of the choroid coat.

The outer edges of the iris are firmly connected with the shell at the junction of the cornea and sclerotic coat, and it is applied pretty closely to the front face of the lens. By the contraction of

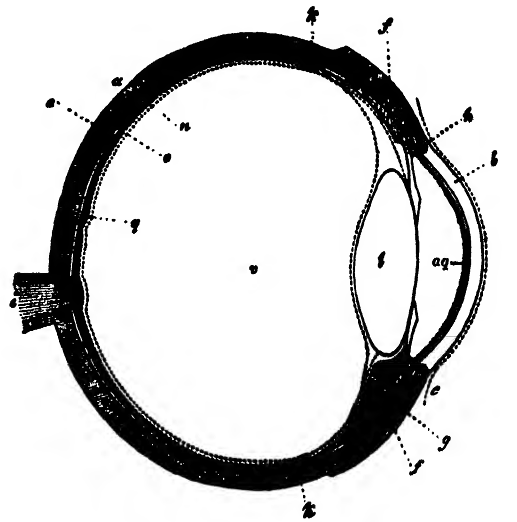


Fig. 1.—Section of the Human Eye.

(*a*) Sclerotic Coat; (*b*) Cornea; (*c*) Conjunctiva; (*e*) Choroid Coat; (*f*) Ciliary Muscle; (*g*) Ciliary Processes; (*h*) Iris; (*i*) Optic Nerve; (*k*) Boundary of Retina; (*l*) Crystalline Lens; (*n*) Choroid Pigment; (*o*) Retina; (*q*) Yellow Spot of Retina; (*aq*) Aqueous Humour; (*v*) Vitreous Humour.

certain circular muscles, with which it is provided, it can lessen the area of the pupil quickly, just as in an old-fashioned purse the drawing to of the strings closes the mouth. It has likewise certain radiating fibres, and the contraction of these enlarges the pupil, as again, we might open the mouth of the purse by pulling at the sides of the bag.

The movements of the iris or coloured curtain of the eye are of extreme interest, showing as they do how very sensitive the eye is to light. There are several ways of watching its movements, one being the familiar looking-glass method. Shut one eye and look into a mirror with the other at the iris. It will be found that upon opening the closed eye the iris, which is being gazed at, will expand very markedly, or, what amounts to the same thing, there will be a marked contraction of the pupil. Other methods the writer has described in a paper read before the Royal Society of Edinburgh,* and as they require no complicated apparatus, we may give them here.

* *Proceedings of the Royal Society of Edinburgh*, Session 1878—9, pp. 36—8; and *Journal of Anatomy and Physiology*, Vol. XIII., pp. 146—8.

The surface of the cornea is moistened with the fluid which forms tears, and as every time one winks this film of liquid is disturbed, it follows from what we know of the influence of rough surfaces on light, that there must be a slight alteration in direction of some of the rays which enter the eye. Regard a distant gas-lamp with one eye closed: beams seem to proceed from the flame like golden bars. These are due to a large extent to the bending influence of this surface-fluid. Whilst looking at the light with one eye, it will be found that there is an alteration in the disposition of the bars at every wink, that is, at every disturbance of this tear-fluid. Now gaze steadily at one of the brightest of the stars, or at a gas-lamp some distance away, and strike a match in front of the face while looking at the star or lamp. Immediately the match is lighted, the bars of light, which seem to project from the star on every hand, retreat into it like the horns of a snail that have just come into rude contact with some unwelcome object (Fig. 2). The influx of more light into the eye when the match is struck causes the pupil to contract, and the rays which appear to stretch out from the star are thus cut off by the iris, until the distant luminary appears only like a dot of light. The next two ways are equally as interesting as this one.

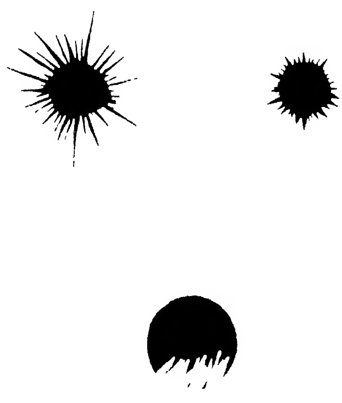


Fig. 2.—A Star seen with Expanded Pupil (a); The Star seen with the Contracted Pupil (b); Illustrating the Pin-head Experiment (c).

Burnish the head of an ordinary brass pin, and then place the pin up to the head in a black hat. Now, with one eye shut, and your back to the light, bring the pin-head near to the other eye, so that light may be reflected into it from the polished convex surface. One sees a circular luminous field, with projecting hairs at the bottom, which belong to the top eyelid (c, Fig. 2). Globules of the tear-fluid also appear at each wink. Now while looking at this circular luminous field, bring up the other hand and intercept the light which is falling into the eye for a moment. When the hand is drawn away, mark the distinct alteration in area of field which is produced; the field contracts most markedly (Fig. 3).

Fig. 3.—The Pin-head Experiment.

For the remaining method we only require a piece of tin-foil in which a minute hole has been pricked with a pin. Upon closing one eye as before, and looking with the other through this hole, placed about half an inch away, any alteration in size of the iris is at once discerned by the alteration in area of the circular field of view.

Substantially the same effects may be observed under very different circumstances. Lying idly on one's back on the grass in the mid-day sun, with the eyes screened by the border of a straw hat, one sees a great number of round holes against the bright sky, and they simultaneously and capriciously alter in size. Were we not acquainted with the foregoing facts, we should little think of referring these alterations to the movements of the iris. Again, if with the back to the light a polished walking-stick be held close to one side of the face, like a fencer guarding that region, the portion of it nearest to the eye presents a bar

of light, which varies in width according as the pupil is expanded or contracted. The ring on one's finger will answer admirably for the pin in the hat experiment, and the reader may often have seen the round circle of light reflected from its surface when in meditative mood he has had his ring-finger near to his eye; he may, moreover, have seen it expand and contract, and have been quite at a loss to account for the phenomenon. These and other facts all prove how very sensitive the eye is to variations in amount of light entering it, a sensitiveness which has been admiringly pondered over by both poet and philosopher. Thomas Moore and Oliver Wendell Holmes each compare the pupil of the eye to bigotry, which the more light you pour upon it the more it contracts, and no doubt some poet of the future will liken the iris, in its beauty, to liberal-mindedness, which the more you illuminate it the more it expands.

We have now taken our optical instrument to pieces, and know the positions of its most prominent parts—cornea, aqueous humour, crystalline lens, vitreous humour, and retina. By a very homely device we may illustrate the use of the more important of these. The apparatus necessary consists of a plain glass flask filled with water, a candle, and two pieces of white cardboard, one of which must have a small round hole punched in it, about the size of a threepenny-piece. Place the flask so that the light of the candle may fall full upon it, and take the unperforated piece of cardboard and fix it upright on the other side of the flask, at such a distance that an image of the candle-flame is projected on to it. The image will appear somewhat blurred, owing to what is known as spherical aberration, or the inability of a lens with spherical surfaces to bring all the rays which fall upon it to the same focus. Now place the perforated cardboard between the light and the flask, and it will be found that the image is very much improved, more distinct and perfect than before. With the completed arrangement we have the apparatus placed as in Fig. 4, in this order—light, perforated cardboard, water-flask, and cardboard screen, and the use of three very important portions of the eye is illustrated, the screen (IV.) representing the retina, the flask (III.) the crystalline lens, and the perforated cardboard (II.) standing for the iris. One of the uses of the iris, then, is to correct any tendency the crystalline lens may have to form a blurred image; and the use of the lens is to project a pretty picture of external objects on to the retina, whilst the latter transmits its impressions through the optic nerve to the brain.

That the action of the crystalline lens is precisely the same as that of our water-flask may be easily

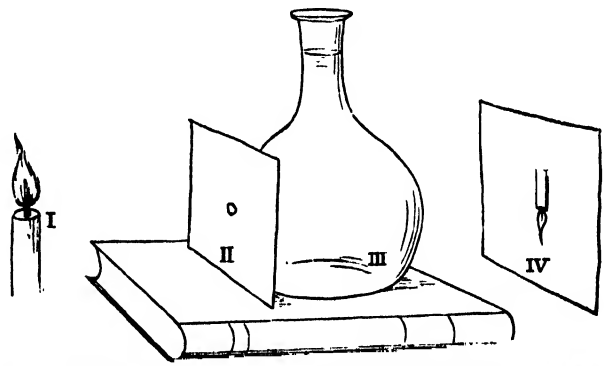


Fig. 4.—Experiment to Illustrate the Use of certain parts of the Eye.

shown. Stick a pin into the edge of the lens that has been kept to experiment with, and now bring the candle on one side of it and a paper screen on the other. A blurred image appears on the screen, and it is *inverted.* Its distinctness is much improved by having here, as in our former experiment, a perforated piece of cardboard or paper to represent the iris.

The iris is said to have another use, which will be well understood after considering the behaviour of a bundle of rays passing through a double convex lens. Since the lens is thickest in the middle and thinnest at the margin, we may look at it as a combination of peculiar glass prisms. Suppose a double convex lens were cut in two, its section would be of the shape shown at *a* (Fig. 5), which is not unlike a section of two prisms base to base (*b*, Fig. 5), and it behaves towards white light like two such prisms. A prism, as the reader is aware, breaks up white light into its "parent colours," red, orange, yellow, green, blue, indigo, and violet,* and in the course of this breaking up violet light is most bent, and red least so. If, therefore,

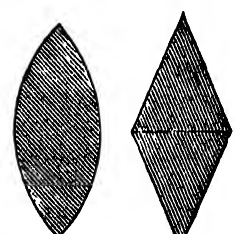


Fig. 5.—Section of Double Convex Lens of two Prism to Base (*b*).

* "Science for All," Vol. I., p. 192.

two thin pencils of white light, *a* and *b* (Fig. 6), be sent into two prisms, placed base to base, it will be readily seen that the violet rays come together at *f* much sooner than the red rays at *f'*, and when a double convex lens is employed to bring together an infinite number of rays of light, it behaves like two prisms placed base to base. In the centre of the field the overlapping of the spectra gives us a white area, but the borders, where no such overlapping can take place, are coloured; the border of the section at s, before any of the rays have been brought to a focus, is of an orange to red tint, and the section of s', after all the rays have been brought to a focus, is of a bluish tinge. This may be seen with an ordinary magnifying glass in the case of the sun's rays. Before the sun's image is well formed the border of the circle of light is of an orange tint, after the focus is past the disc of light is fringed with blue. Double convex lenses all behave in this way, a peculiarity which is termed *chromatic aberration.* If this fringe were cut off by means of a ring-like screen, it is evident that inconvenience arising from this aberration would be overcome. Ring-like screens of this kind are, therefore, employed inside telescopes for this purpose; and many eminent men maintain that in the iris we are supplied with a ring-like screen which neutralises any tendency the crystalline lens may have to exhibit this defect.

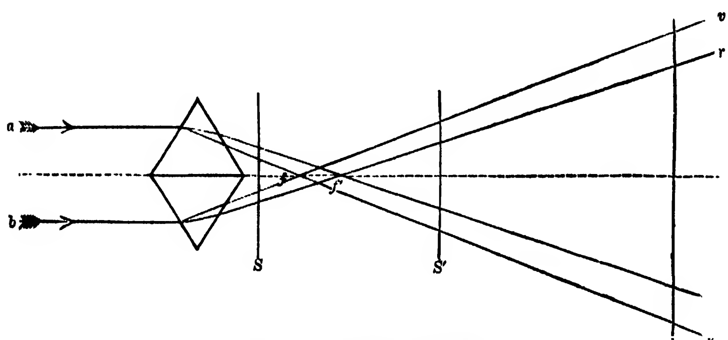


Fig. 6.—Chromatic Aberration.

In darkness we see nothing, nor can we see anything in daylight if the eyes be closed. Immediately, however, the eyes are opened, we become conscience of the existence of external objects; their images are cast upon the retinæ, and in some wonderful manner the facts are flashed along the optic nerve to the brain. This action of light upon the retinal membrane is one of the most marvellous that we are acquainted with, not that there is a lack of surprising facts concerning the power of a beam of light, for we know that it is an agent that has a peculiar and potent influence in the three kingdoms of nature. The work done by it in the green leaves of trees must be something enormous, and had we the proper data it would be an interesting problem to ascertain how many millions of tons of wood are yearly produced by its chemical action on the carbonic acid floating in the air. Its influence on vital phenomena is somewhat surprising, it being a well-known fact that the healthiest portions of a hospital are those wards which are best lighted. The prolonged absence of light would be a very serious matter, for an eternal night on the face of the earth would probably lead first to death and disease, and finally to a sightless animal creation. Note the effects of an Arctic night in Smith's Sound as described by Dr. Kane:—

"*Dec. 15th, Thursday.*—We have lost the last vestige of our mid-day twilight. We cannot see print, and hardly paper; the fingers cannot be counted a foot from the eyes.

"The first traces of returning light were observed at noon on the 21st January, when the southern horizon had for a short time a distinct orange tint. . . . We had been nearing the sunshine for thirty-two days, and had just reached that degree of mitigated darkness which made the extreme midnight of Sir Edward Parry in latitude 74° 47'. Even as late as the 31st, two very sensitive daguerreotype plates, treated with iodine and bromine, failed to indicate any solar influence when exposed to the southern horizon at noon; the camera being used in-doors to escape the effects of cold. The influence of this long, intense darkness was most depressing. Even our dogs, although the greater part of them were natives of the Arctic Circle, were unable to withstand it. Most of them died from an anomalous form of disease, to which I am satisfied the absence of light contributed as much as the extreme cold. I give a little extract from my journal of January 20.

"'This morning at 5 o'clock—for I am so afflicted with the insomnium of this eternal night that I rise at any time between midnight and noon—I went upon deck. It was absolutely dark, the cold not permitting a swinging lamp. There was not a glimmer came to me through the ice-crusted window-panes of the cabin. While I was

feeling my way, half puzzled as to the best method of steering clear of whatever might be before me, two of my Newfoundland dogs put their cold noses against my hand, and instantly commenced the most exuberant antics of satisfaction. It then occurred to me how very dreary and forlorn must these poor animals be, at atmospheres + 10° in-doors, and − 50° without, living in darkness, howling at an accidental light as if it reminded them of the moon, and with nothing either of instinct or sensation to tell them of the passing hours, or to explain the long-lost daylight. They shall see the lantern more frequently.'"

Now, suppose an animal, untold ages ago, had been placed in darkness, kept there, and all its descendants after it—what would have happened? An organ that is never used decreases in size, and in the course of ages may disappear. It is highly probable, therefore, that after a few generations the eyes of these confined animals would be diminished in size and sensitiveness, and that finally they would become stone-blind. It is thought by many scientific men that the blind fishes and insects which inhabit the "Mammoth Caves" of Kentucky have had some such history, and are the descendants of originals still represented by perfect forms outside. From the foregoing facts it follows that the absence of light is injurious, and its presence beneficial to animated nature. Nor is its influence on inorganic matter of less importance. We have seen that it materially influences the electrical conductivity of the element selenium,* and as a quality is seldom isolated, but possessed by a host of other bodies to a more or less degree, light has probably this action on other substances. When absorbed it may be turned into heat, or employed in effecting chemical changes, as in the photographer's iodised plate. Books, sometimes, which have lain for years and years side by side, with only the titular portion of the backs exposed to the sun's rays, exhibit a marked difference in the colour of their covers, the backs being decidedly paler than the sides. The bird-stuffer, aware of this action of light, takes good care to paint the plumage of his birds with more stable colours; and the careful curator, long tormented with the destructive action of light on the gaudy colours of his butterflies, now endeavours with tinted glass to sift the sun's rays of what he has found to be their most destructive parts. This bleaching action is exhibited in a remarkable degree in the case of the retina. After Prof. Fr. Boll announced the discovery that the outer layer of the retina—*i.e.*, the layer farthest from the vitreous humour—is in the living condition not colourless, but of a purple-red colour, and that the colour is being continually destroyed by the light which enters the eye, this subject became of the utmost importance, and ere long Dr. W. Kühne, Professor of Physiology in the University of Heidelberg, ascertained that this colouring matter, termed the *visual purple*, may be bleached by light *after death*, an important discovery, inasmuch as many experiments could now be made on removed retinæ, which before would have seemed useless, or impossible. To show the influence of solar light, Kühne took ten uniformly purple retinæ of frogs (*Rana temporaria*), and spread them out in a row touching each other; he placed the retinæ in a spectrum of the sun's light obtained by passing a bundle of rays through a flint-glass prism, so that some were exposed to ultra-red and red rays, others to violet and ultra-violet rays, and the remainder to the light of the rest of the spectrum. It would appear that where there was the greatest absorption of light, the bleaching of the exposed retinæ was soonest effected. After his experiments, Kühne was able to affirm that light of one colour bleaches and decolourises the colouring matter of the retina, as white light does, only very much more slowly; that of all one-coloured lights the following act with decreasing rapidity: greenish-yellow, yellowish-green, green, bluish-green, greenish-blue, cyanogen-blue, indigo-blue, violet, later pure yellow and orange, and still later ultra-violet and red; that the extreme red and ultra-violet rays are not entirely without action, but that the commencement of the ultra-violet is more active than the commencement of the visible red. He points out, as a most significant fact, that precisely those rays which most affect our eyes, and appear to be the most intense—namely, the greenish-yellow—are those by which the colouring matter of the retina itself is the most changed. Seeing then that the retina is the eye-screen, and that it is materially influenced by the action of light, it now behoves us, because of its importance, to inquire more particularly into its structure, and the uses of its various parts.

The retina is a perfectly transparent membrane, varying in thickness from an eightieth to a little less than a hundred and sixtieth of an inch, and lines the interior of the wall of the eyeball, as we have seen. A thin vertical section of it at any spot except the exact centre (called the yellow spot) and

* "Science for All," Vol. III., p. 58.

the entrance of the optic nerve, when viewed under the microscope, presents us with the structures represented in Fig. 7. From *b* to *h* the nervous element is held together by what is termed connective tissue, and beyond *h* the remainder of the retina consists of peculiarly-shaped nerve filaments, some like

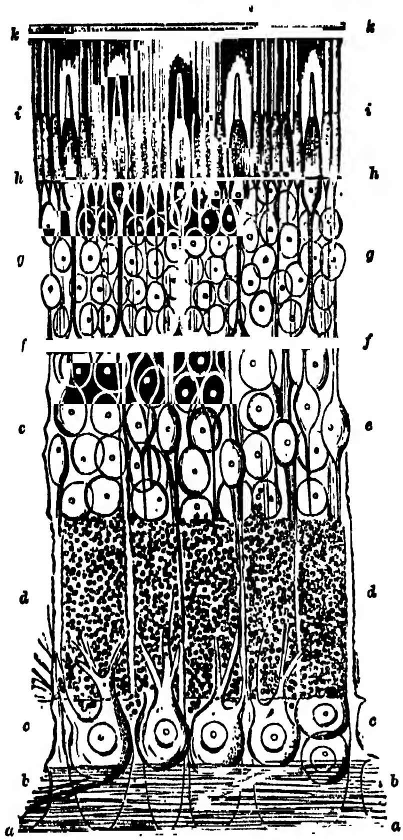


Fig. 7.—Section of the Human Retina.

(*a*) Surface of the Retina in contact with the Vitreous Humour; (*b*) Expansion of the Fibres of the Optic Nerve; (*c*) Ganglionic Corpuscles; (*d*) Molecular Layer and Nervous Fibres; (*e*) Inner Granules and Nuclei; (*f*) Intergranular Layer, and interwoven Nervous Fibres bearing the Inner Granules; (*g*) Granules of the Outer Layer; (*h*) Outer Limiting Surface where the Rods and Cones start, and Connective Tissue ceases; (*i*) Rods and Cones; (*k*) Limiting Surface in contact with the Pigment of the Choroid Coat.

staves and called *rods*, and others of a sugar-loaf form, termed *cones*. In Fig. 8, three of these cones and six rods are shown on a larger scale.

Where the optic nerve enters the eye it spreads out its filaments in all directions, forming the fore-part, *b* (Fig. 7), of the retina; and these, doubtless, are in connection with the rods and cones at the back. The intermediary structures are stated in the detailed inscription to Fig. 7.

One would naturally suppose that the portion of the retina turned towards the light would be the part which is affected by it; we shall see, however, as we proceed, that such is not the case, but that these rods and cones at the very back of the retina are the agents which *feel* the light after it has passed through the transparent parts which lie in front. There are minute blood-vessels in the retina, ramifications of the artery which enters the eye along with the optic nerve, and they are spread out in the portion of the membrane which lies between the layer of rods and cones and the surface in contact with the vitreous humour. Evidence of their existence may be easily obtained without even having recourse to dissection. Let the reader try the following simple experiment upon himself, by means of which he will see the shadows of the vessels like the black and bare arms of a tree seen against a red sunset sky. No light must be in the room save that of a candle, and this must be employed in the following way:—Close one eye, and with the other stare into the dark vacancy. Now move the candle-flame up and down near to the outer side of the open eye, so that the

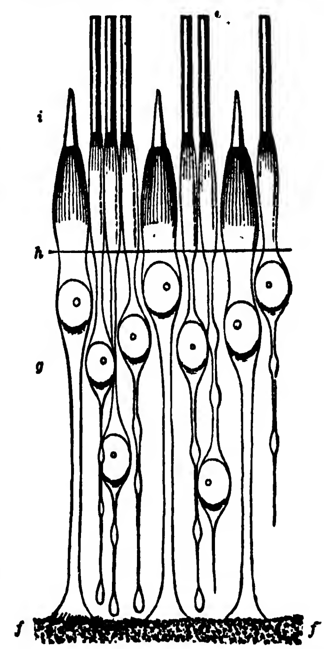


Fig. 8.—The Rods and Cones on a larger Scale; there are three of the latter between six of the former.

light enters it in a slanting direction. Under these circumstances the reader will see a series of diverging black lines against a red ground, which are known as *Purkinje's figures* * (Fig. 9). For the success of the experiment it is very necessary to keep the candle moving. Sir Charles Wheatstone invented an instrument for showing an original variation of this experiment. It consists of a circular plate of metal about two inches in diameter, blackened at its outer side and perforated at its centre, with an aperture about half an inch in diameter. To the inner face is fixed a similar plate of ground glass. On placing the aperture between the eye and the flame of a candle, and keeping the plate in motion, so as to displace continually the image of the aperture on

* In some of our best physiological text-books the idea is given that *bright* lines on a *dark* ground are seen—a curious mistake.

the retina, the ramifying lines are seen distributed as before, but brighter. In the very centre of the field of vision there is a small circular space, in which no traces of vessels appear; this is the most sensitive portion of the retina. When this portion

Fig. 9.—How to see *Purkinje's Figures.*

of the retina is examined it is found to be full of close-set cones, a fact which, taken along with another we shall now mention, seems to show that these cones are the portions of the retina which are sensitive to light. Where the optic nerve enters the retina there are no cones; this spot is blind. We have experimentally ascertained that the optic nerve enters the eye a little to one side of its central part, and as the eye rests in the head it is the side

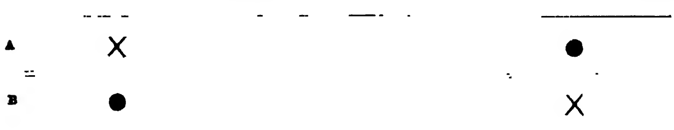


Fig. 10.—Testing for the Blind Spot in each Retina.

nearest the nose where the nerve enters. The following experiment proves that the point of entrance is not sensitive to light. Close the left eye, and regard the cross (Fig. 10, A) steadily with the right, held say eighteen inches away. Now bring the paper gradually nearer, keeping the gaze fixed on the cross, while, however, an effort is made to keep the white circle in sight without turning the eye away from the cross. As the cross nears the eye, a position is reached where the white circle disappears. Upon continuing the approach of the cross, the white circle comes into view again. Now close the right eye and follow precisely the same directions with the following circle and cross (Fig. 10, B), keeping the eye steadily fixed on the cross as before. It will be found again that at one stage of the approach of the cross the white circle disappears. This experiment proves that there is a spot on each retina on its nasal side which is blind; this spot is the entrance of the optic nerve, which has accordingly been called the *punctum cæcum*, or blind spot. In Fig. 11 we have endeavoured to represent the conditions in these two experiments. Three positions of the circle and cross with respect to the eyes are shown. In the second position, where the image of the circle rests in each case on the blind spot, the circle cannot be seen. It has again come into sight by the time the third position is reached, and when the image no longer rests on the entrance of the optic nerve. These two facts then, that there are no cones in that spot of the retina which is blind, that there are cones nearly to the exclusion of other elements in the spot of retina where vision is most acute, would lead us to suppose that these cones are in some way concerned in the phenomenon of vision. Nocturnal birds, like owls, are said to have very few cones, and the eel, which lives in dark mud, none at all. The mode of occurrence of Purkinje's figures likewise points to the region of the cones as being that which is influenced by light. In producing these figures the light falls on the inner surface of the retina, so that whatever perceives the shadows of the blood-vessels will necessarily lie on the other side of them, namely, in the locality of the rods and cones.

The question arises, What makes this layer of the retina sensitive to light? Can it be the peculiar form of the rods and cones which are adapted to take up ethereal wave-motion, or can it be because in this region there is that colouring matter which is known as the *visual* purple? The working out of the question has so far proved a most baffling inquiry, and we cannot do better here than give the results of the most recent research.

Some have supposed that the retina, like the sensitised plate in a photographer's camera, is a membrane upon which the light acts and prints images of external objects. It is noteworthy, however, that the philosopher to whom we owe much evidence that would seem to support this hypothesis, thinks that the retina, so long as it is maintained in its natural connections with the *pigment* of the

choroid coat, resembles not so much a photographic plate as a whole photographic workshop, in which the operator, by bringing new sensitive material, is always renewing the plates, and at the same time washing out the old image; for Kühne, to whom we refer, found that the visual purple could be renewed upon bringing a bleached retina into contact with the layer of pigment which lines the choroid coat. And here we may remark that this pigment forms the natural support of the rods. The pigment when viewed under the microscope appears to be formed of six-sided particles, arranged side by side as represented at *a* (Fig. 12); *b* is a side view of two of these particles, and at *c* one is seen with retinal rods embedded in it.

Fig. 11.—How we perceive the Insensibility of the Blind Spot. The dotted lines show the direction of the optic nerves until their junction upon entering the brain.

Kühne recounts some other remarkable experiments, a few of which we may here describe as bearing on this subject.

On one occasion a frog exposed only to blue light kept its eye steadily fixed on the flame. After fourteen hours' exposure it was found that a beautiful image of the gas-light had been photographed on the retina, appearing perfectly colourless on a deep red ground. It will be observed that we have here a phenomenon analogous to what would take place in our experiment, represented in Fig. 4, supposing the screen IV. were coloured, and the light had the power to imprint its white likeness on it.

These *optograms*, or retinal photographs, are not easily obtainable, and Kühne had long tried to get them in the eyes of the larger mammals before he was successful in the case detailed above. One of the difficulties in the way of successful optography arises from the fact that the front layers of the retina become opaque in death, and as the visual purple is in the region of the rods and cones at the back, the light can evidently not penetrate so far. Kühne accordingly found it necessary to remove and invert the retina for optographic purposes. Whilst treating of this matter, he is careful to remark that there are not wanting imaginative persons who profess to have seen in the eye of a murdered person the image of the murderer, but for his part he cannot corroborate their wild assertions.*

* The reader who may be desirous of learning more about the *visual purple* will do well to peruse Foster's translation of Kühne, "On the Photochemistry of the Retina and on Visual Purple."

This photographic change of the retina under the influence of light is associated with a change in its electrical condition, and just as various kinds of light bleach the visual purple in different degrees, so in like manner various kinds of light influence the electrical condition of the retina in different degrees. To ascertain this, Messrs. Dewar and McKendrick experimented on a great number of animals—snakes, frogs, toads, newts, gold-fishes, stickle-backs, rockling, the common crab, the swimming crab, spider-crab, lobster, and hermit-crab. They were able to show that in each of these cases when light falls on the retina its electrical condition is altered, and afterwards they ascertained the same fact with regard to the cat, rabbit, pigeon,

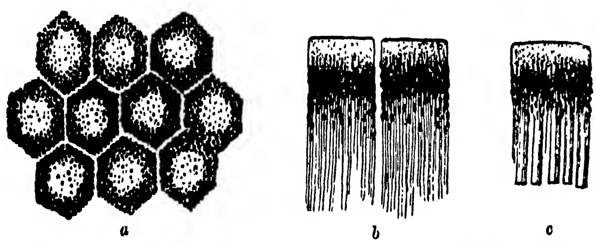


Fig. 12.—The Black Pigment of the Choroid Coat. (a) Six-sided Particles of Pigment; (b) Side-view of two; (c) one with attached Rods.

and owl. Some of the results of their series of elaborate experiments are these :—

1. That the specific effect of light on the eye is to change the electrical condition of the retina and optic nerve; 2. That the change is in agreement with Fechner's law;* 3. That those rays, such as yellow, which appear to our consciousness to be the most luminous, affect the electrical condition the most; and that those, such as violet, which are least luminous, affect it least; that this electrical change is essentially dependent on the retina, because if this structure is removed, while the other structure of the eye lives, there is no sensitiveness to light.

These two phenomena, then, the bleaching of the retina and its electrical change, are probably both concerned in the act of vision, and more especially the latter, for there may be something more than analogy in experiments like that of Siemens,† wherein an artificial eye is made to vary the indications of a galvanometer with each alteration in colour or intensity of the light entering it.

* Vol. II., p. 308. † Vol. III., p. 59.

Now we are in a better position than when we started to inquire into the reason why we perceive external objects so well in daylight. The light reflected from these bodies, varying in colour and quantity, enters the eye, and by means of its media forms a perfect image at the back; wonderful changes are all the while going on in the substance of the retina, varying in amount with the nature of the image on it, and intelligence of these changes is transmitted along the optic nerve in some way, to produce in the brain an idea of what is before the observer. The growth of this power, from the "evolutionist's" standpoint, we cannot give in better words than those which were used by Professor Tyndall, in his memorable Belfast address to the British Association:—

"In the lowest organisms we have a kind of tactual sense diffused over the entire body; then, through impressions from without, and their corresponding adjustments, special portions of the surface become more responsive to stimuli than others. The senses are nascent, the basis of all of them being that simple tactual sense which the sage Democritus recognised 2,300 years ago as their common progenitor. The action of light, in the first instance, appears to be a mere disturbance of the chemical processes in the animal organism, similar to that which occurs in the leaves of plants. By degrees the action becomes localised in a few pigment-cells, more sensitive to light than the surrounding tissue. The eye is here incipient. At first it is merely capable of revealing differences of light and shade produced by bodies close at hand. Followed as the interception of the light is in almost all cases by the contact of the closely adjacent opaque body, sight in this condition becomes a kind of 'anticipatory touch.' The adjustment continues; a slight bulging out of the epidermis over the pigment-granules supervenes. A lens is incipient, and, through the operation of infinite adjustments, at length reaches the perfection that it displays in the hawk and the eagle."

Here for the present we may suspend our inquiries. In another paper we propose to tell about the eye and visual phenomena what we have now left unsaid.

A LEAD-MINE.

By G. A. Lebour, M.A., F.G.S.,

Professor of Geology in the University of Durham College of Physical Science, Newcastle-on-Tyne.

Although we need not give our lead-mine a name, yet must we give it to some extent a local habitation, for lead-mines are not situated haphazard over the face of the country. They occur according to certain rules. Of these rules there are some that we do not yet fully understand, but most of them have, by dint of the practical experience of centuries, become part of the common knowledge of every miner.

In England, lead-veins (if they be meant to "pay") are to be sought for in the older rocks only, and more especially in those of Carboniferous (Frontispiece to Vol. I.), Devonian and Silurian ages. Hence, our search for a lead-mine worth visiting is limited to the districts where these formations predominate, or, roughly speaking, to the extreme western counties, Wales, the Lake district, Derbyshire, Durham, Cumberland and Northumberland.

Let us select the region in which the three last-named northern counties meet: that known as Alston Moor—an area which, although now all but abandoned by the lead-miner, was for many years, and may perhaps once more become, a very store-house of the heavy, homely metal. Here we have a country of deep valleys, high and broad undulating moorlands, and, connecting the two, numberless narrow, often wooded, glens, or "gills," down which pour the black peaty waters from the heather-clad uplands to the rivers, laying bare the strata, or "sills," of which the hills are formed, with many a leap, "force," or waterfall over the hardest of them.

Now, these beds, or "sills," as they are locally called, are chiefly of three kinds—*Shale*, or hardened, slabby mud; *Sandstone*, or hardened sand; and *Limestone*, or hardened, calcareous or limy sea-bottom ooze. The shales, being the softest, are more quickly worn back than the other rocks by the action of the water, and the waterfalls are thus limited to the sandstones and limestones. There are a very great number of these beds following one another without any apparent order, some thin and some thick, so that if the rare soil be removed from one of the hill-sides, the effect would resemble that shown in Fig. 1.

The sandstones and shales are both more frequent and thicker than the limestones, yet the whole of these rocks belong to the great Carboniferous Limestone series; and although the calcareous beds make so poor a show when compared with the great limestone masses of the same age in Derbyshire and Wales, they are nevertheless by far the most important "sills," in the eyes of the lead-seeker. One result of this is that each seam, or band, of limestone has its own special name by which it is known throughout the region—the "Great," the "Little," the "Four-fathom," the "Tyne-bottom" limestone, or some other derived from local peculiarity, thickness, or position.*

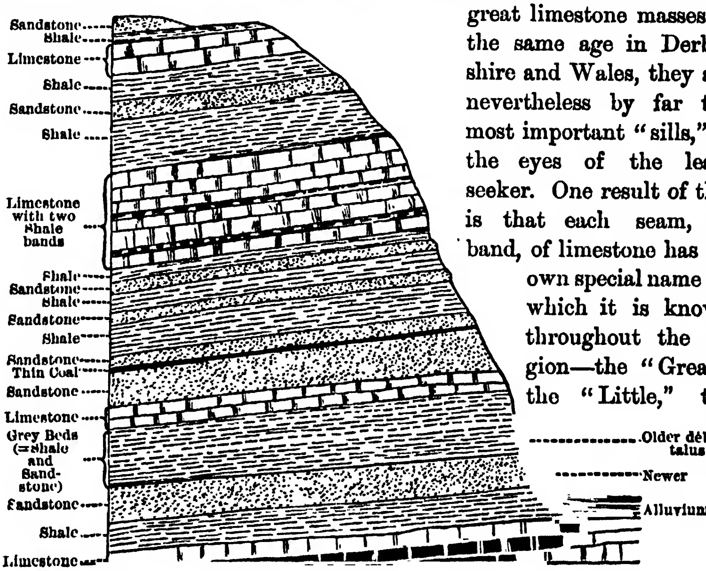


Fig. 1.—Section of Hill-side showing Beds, or "Sills," of Shale, Sandstone, and Limestone.

All these rocks together form what is called the "country" by the miners: that is, the unchanging deposits in which the veins occur; and, by experience, the miners know well, in a general way, in what particular portions of the "country" rock the veins are likely to prove most productive of lead-ore.

* Besides the rocks mentioned, there are a few coals in the Carboniferous Limestone series of this region, and also a thick sheet of intrusive basalt, known as the "Great Whin Sill," the word "sill" being applicable to it from the fact of its lying for considerable distances between the same beds, as a sedimentary rock would do. Mention of the coal and trap is purposely omitted in the text for the sake of avoiding unnecessary detail.

As we travel along one of the deep valleys—that of the South Tyne, for instance, above the old-fashioned, steep-streeted mining town of Alston—the above-mentioned sills are easily distinguished running in nearly level parallel lines, scoring and ridging the hill-flanks on either hand. At first this is all of the geology of the place that is obvious to us. A little closer observation, however, will soon reveal, at unequal intervals, series of small dark openings—like doors in the mountain—each with a large or small heap of rock fragments in front of it. Each series of openings, or tunnel-mouths—for such they really are—runs *across* the beds. In other words, the tunnels ("drifts," "levels," or "adits" are the technical terms) forming each set of openings are driven along a vertical, or nearly vertical, fissure, or crack—long ago filled up, probably—cutting through and dividing asunder the flat-lying beds of the "country" rock. This filled-up fissure, or crack, is a vein. The stony fragments at the "level" mouths consist for the most part of the filling-up matter of the vein, and is called "vein-stuff;" and not every geologist would care to be asked more accurately to name every substance of which this is composed, for it is a very omnium-gatherum of minerals and rocks. Here, however, in South Tynedale, calcite, or carbonate of lime in dog-tooth or nail-head crystals, or again as a water incrustation, or stalagmite, is found in quantities, together with a somewhat similar-looking, but much heavier mineral—heavy-spar, or sulphate of barytes, and witherite, or carbonate of barytes. Prettier than either of these, and in places even more common, are more or less perfect cubes of violet, light blue, red, pink, green, or yellow fluor-spar—the Blue John of Derbyshire—for which Alston Moor has long been famous among collectors, and brilliant, diamond-like but six-sided crystals of quartz. All these minerals, and others, are seen coating or traversing in every direction rough angular masses of hardened and altered limestone—how altered we do not exactly know; and among the whole mixture of what a miner would call "mineralised" rock, we are pretty sure to find scattered bright, golden, shining crystals—cubes again—of iron-pyrites, and better still, other cubes or blotches or lumps of a dull grey, heavy substance. This is the lead-ore, or galena, and upon the amount of it to be found in each vein, or in each part of a vein, depends the value of the latter.

A blow from our hammer will break up one of the dull grey lumps of ore into bright, shining, steel-like, square-sided fragments, which exposure to the air will in time again render grey and dull on the outside. Now, this galena is not pure lead, or else our hammer would have flattened it instead of breaking it up into sharp crystalline pieces; it is "plumbic sulphide," a compound of lead and sulphur, in the proportion, when pure, of 86·61 per cent. of the former, and 13·39 per cent. of the latter. Galena is, however, seldom absolutely pure, and one of its commonest impurities is, fortunately for us, of greater value than lead. It is silver which is almost always present in lead-ore, and sometimes in such considerable quantities that the latter is worked entirely for its sake. Indeed, the "de-silverisation" of lead is one of the most important metallurgical processes in connection with this metal, and one which owes its chief improvements to a worthy of this very district of Alston Moor, the late Mr. H. L. Pattinson.

Now, let us each take a lump of soft clay, and in it stick a lighted tallow candle, and then grope our way as best we can into the hill along any one of the levels. Wet and dirty work certainly, not to be undertaken in fine clothes, but worth going through if at the end of the low, narrow, propped-up gallery we come to the face of the vein—to the place, that is, at which work was left off. Here, for the first time, we have a chance of seeing what a vein is really like. We have seen its several parts outside, but now the puzzle-parts are pieced together in their proper relative positions. The vein-stuff and ore are seen intertwining together in places, but a general up-and-down banded arrangement of the various mineral substances can be easily distinguished, as a rule, running parallel to the sides of the fissure—the "cheeks" of the vein. Sometimes the vein may be yards in width, oftener but a few feet, sometimes but an inch or so. Sometimes the vein is a single one, and sometimes it is split up into a number of tiny veinlets, or "strings." Sometimes the entire space is filled with ore, sometimes with one or other of the vein-stuff minerals, to the temporary exclusion of the others. Thus a well-known vein in Northumberland, formerly profitably worked for lead, is now, and has been for years, worked merely for the carbonate of barytes with which it is filled, whilst galena is only occasionally met with in it. A vein is therefore divided into rich parts and poor parts. Of these, the former alone concerns the practical miner, and the observation of ages has shown that their occurrence depends mainly upon three points—(1) the direction of the vein; (2) the amount of its deviation

from the vertical; and (3) the nature of the "country" rock.

Each metal-mining region must be regarded as a more or less intricate network of veins running in different directions, and in each case it is found that one general direction (within a range of 30° or so) is affected by the ore-bearing veins, the others being mainly filled with vein-stuff and comparatively valueless. In the district in question the direction in which the best veins run lies between east and west and south-east and north-west. Such veins are said to be "right-running," in contradistinction from the others, which are called "counter" veins. There has never been given a satisfactory explanation of this law of direction, but notwithstanding many exceptions, it *is* undoubtedly a law.

The other two points are not so obscure. In right-running veins there are, as has been said above, relatively richer and poorer portions, and attentive study of the circumstances under which these occur seems to show that the richer parts must be looked for where *both* cheeks of the vein are of hard—not *too* hard, but *moderately* hard—rock, and where the vein is most vertical.

When a vein is the infilling of a crack or fissure only, and when the beds of the "country" rock are, as in the case under consideration, horizontal, both cheeks must necessarily be alike. But more often the crack is something more than a mere fissure; it is generally a line of displacement, along which one side of the "country" has been forced up or down —usually down—from its original position; or in geological parlance it is a "fault" as well as a vein (see Figs. 2 to 4). Where different kinds of rock alternate as rapidly as they do in this Alston country, it is natural to suppose that the effect of a dislocation, or fault, will in its details be other than would be the case in a uniform rock-mass of great thickness. In practice such a difference is found to exist, more especially as regards the amount and variability of "hade" (as the angle of deviation from the vertical is called). In a uniform hard rock the hade of a fault or vein is usually most regular and most nearly approaches the vertical; in uniform soft rocks it is most oblique; but in alternating hard and soft rocks the hade is variable, changing in amount according to the nature of the cheeks, and more erect in the hard zones than in the soft.

Now, if the reader will cut a piece of paper into two parts so that the dividing line be made to represent such a variable hade—like the line v v in Fig. 2, for instance—and if one of the pieces be then shifted a little downwards *in the direction of the hade*, he will have a good model of a fault-vein in a region like this of Alston Moor (Fig. 2).

It will be noticed that the vein, instead of being a mere line, as it would be had the hade been a regular one (Fig. 3), is alternately narrow and wide. Moreover, it will be seen that it is widest

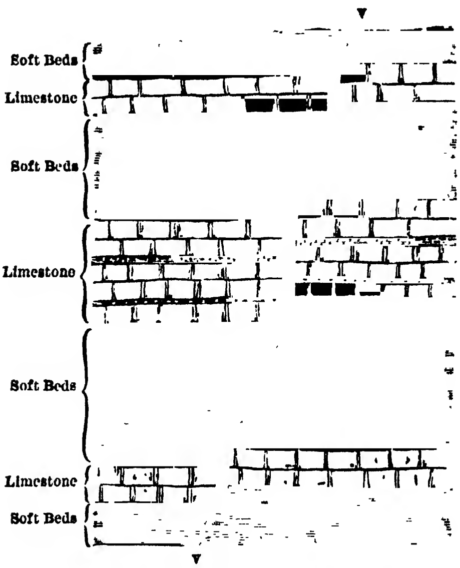


Fig. 2.—An Ordinary "Fault" Vein.

where most erect, or, in other words, in the hardest rocks. And this it is that has given rise to one of the most universally true of the lead-miner's rules, viz., that the steepest parts of a vein are also the

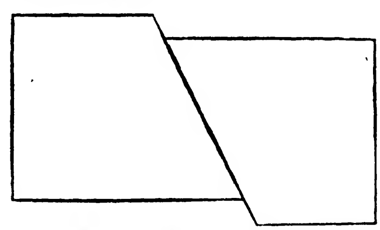


Fig. 3.—Showing Vein where the "Hade" is Regular.

richest. Indeed, the few known exceptions to this rule are almost limited to the rare cases where the vein is what geologists term a *reversed fault*, *i.e.*, where the beds on the overlying side of the hade-slope are on a higher level than on the underlying (Fig. 4). Here there are a few examples of this sort and *then* the veins have been found to be widest in the soft beds, where the cheeks are unfavourable to the accumulation of ore, and where they are most upright. Mines in such veins have seldom proved remunerative.

One result of this step-like structure of many veins is, that the broad steep portions were, prior to their infilling, so many long passages shut in above and below, and thus separated from each

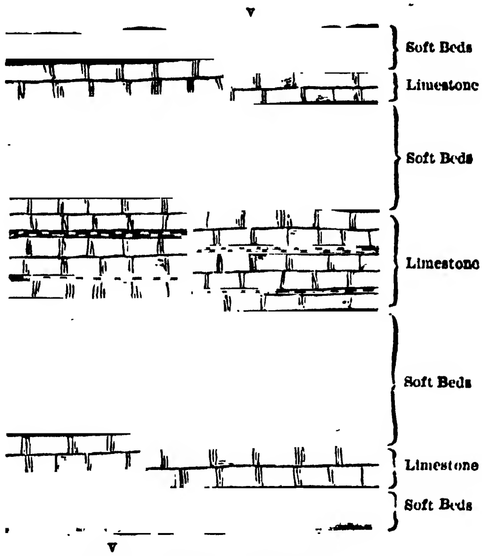


Fig. 4.—A Reversed "Fault" Vein.

other by the soft beds. The latter, being usually clays or shales, are more or less impervious to water, and the long passages were therefore admirably adapted for the circulation and retention of mineral and thermal waters, and their occasional isolation in this manner may enable us to understand how both ore and spar may have at times been localised, as they are so frequently found to be—occurring in abundance at some levels, and being absent at others.

The limestones, which, as has been seen, are the hard and ore-bearing rocks *par excellence* of this district, are disposed in beds (or, as they are locally called, "posts") of moderate thickness, and varying in number in each limestone. These "posts" are often separated by thin bands of earthy limy shales, and each one is cut up by a system of vertical joints, so that an open face of limestone somewhat resembles a few courses of Cyclopean masonry. This arrangement of each limestone into "posts" is very important as regards lead-mining here, for not only do the veins hold most ore between cheeks of this kind of rock, but they, when in this position, sometimes send offshoots of rich vein-stuff of variable length out from the parent mass into the stone, as it were, filling up the flat spaces between the "posts" of limestone. Such ore-deposits are appropriately called "flats" in this region, and are almost peculiar to it. Although they are limited in extent, thinning away as they recede from the vein, they yet add vastly to the value of even the richest lode (Fig. 5).

Again, lead-ore and veinstuff are frequently found filling some of the cavities which are so common in calcareous rock, where they are eroded by the action of water charged with carbonic acid. Such caverns full of ore are always, or have at some time been, connected with existing, or formerly existing lodes, just in the same way as the "flats." They are known as "pockets" by the miners; and although very rich whilst they last, their yield is, from their very nature, less to be relied on than that of the flats.* Fig. 6 shows, in section, a pocket of this kind which was accidentally cut through about thirty years ago in one of the Alston mines, and which was quite full of very fine galena, with a very small admixture of spar. The discovery of such deposits, unlike those previously described, is purely a matter of chance.

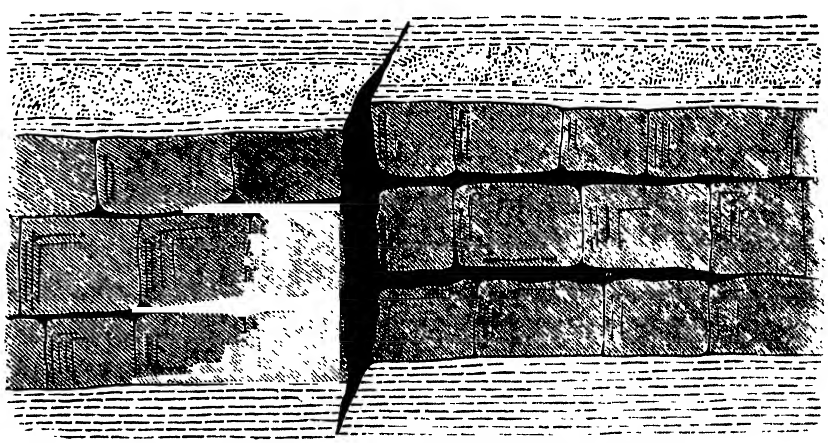
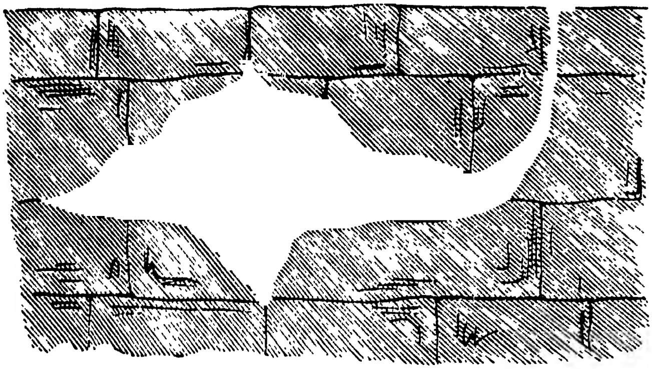


Fig. 5.—Showing Vein with "Flats" in a Three-"post" Limestone.

* The term "pocket" is often misapplied to specially rich and broad masses of ore in the vein itself. Such masses are more properly called "bunches."

Having now seen how lead-ore occurs in the Great Northern Lead Measures, let us leave the veins, ordinary and reversed, "flats" and "pockets," to slumber in what miners delight to call the



. 6—Section of "Pocket."

"bowels of the earth," and let us retrace our steps to the outer air, with the assurance that in whatever other mineral district we may be there galena will be found in similar positions, the chief differences being only such as are directly due to other conditions of "country." Nowhere can the lessons of the veins be learnt better than among these old deserted mines.

But students of Nature must not rest satisfied with a mere description of modes of occurrence of certain minerals. Various questions must be asked and carefully considered. How did the lead get there? How did the veins, "flats," and "pockets," get filled with galena, quartz, heavy-spar, calcite, and fluor-spar? Modern science is now busy finding out answers to such questions. Quartz, heavy-spar, and calcite have been reproduced in our laboratories by the action of water under certain conditions of pressure and temperature. Galena, on the other hand, has been reproduced in what is called the "dry way," by sublimation—by the action of fire. This kind of investigation is known as "synthetical mineralogy," and its results are calculated to throw a flood of light upon the entire subject of metalliferous deposits. At present, suffice it to say that nothing has as yet been advanced which is incompatible with the theory that both ore and spar are deposits due to the long-continued action, under pressure, of hot mineral springs. But there need be no denial of the possibility of other modes of formation in certain cases. The "synthetical" mineral makers have been able to reproduce the same minerals by very various methods, and Nature, we know, loves to attain her ends by more ways than one.

THE SCENERY OF THE SHORE.

By Charles Lapworth, F.G.S., etc., Madras College, St. Andrews.

Of all the sights that meet the eye of the habitual dweller in an inland district of a country so little diversified by abrupt physical features as our own, there is none that charms him so greatly at first sight, or retains its peculiar attractions unchanged for so many years as the view of the sea-shore. The portion of the coast-line that first greeted his unaccustomed eyes may possibly have been some picturesque fragment of our western shore, where the dizzy cliffs plunge sheer into the depths of the Atlantic. Or it may be a part of our softer eastern coast, where league after league of yellow sand borders the fertile farm-lands like golden fringes. Or, what is far more likely, the silent sea first dawned upon him as he floated out upon it, over the spreading bosom of some vast estuary, where the sight of the slow-receding shores, and the ever-widening waters, awed him into his first true idea of its limitless expanse. Wherever it may have been, it was certainly to him a turning-point in his life, a day of strange emotions, unfelt before, and never to be forgotten.

Even to the constant dweller upon the sea-coast, familiar to the shore from his earliest boyhood, it is doubtful if the sight ever becomes trite or stale. He lives at the very boundary-line between the known and the unknown, between life and death. On the one side is the solid land, dead, impassive, clothed in its green immobile pall, the lifeless embodiment of stability and permanence. Not a mound, not a cliff, but bears the visible impression of wearing the same features that marked it at its origin. Whether seen full and clear in the brightest

sunlight, or caught vaguely, half shrouded in mist and fog, the same familiar outlines are ever recognisable, the very images of stability, unchanged and unchangeable.

How different the mobile sea, never the same in its aspect for a single moment! Its surface, as far as the straining eye can reach, is in a state of continual movement. Even when the air is at its stillest, and all else seems asleep, its hissing rollers chase each other over the shallows, and its billows dash themselves into white foam upon the cliffs. From the shore to the long level horizon, it is instinct with a multitudinous, all-pervading life.

This wonderful contrast, seen nowhere else, forms perhaps the main foundation of our keen enjoyment of the view of the sea-coast, and gives it its most peculiar charm under every aspect. But the main source of our delight, as we wander along the sea-shore, is, undoubtedly, the endless variety in the coast scenery, afforded by frequent changes in the form and contour of the land as we pass from point to point, and the contrast of this rise and fall of the land with the never-varying level of the ocean.

The coast of Britain yields us these pleasant changes in endless variety. In one spot, as at Brighton, the shining beach of sand, wet with the ebbing tide, stretches out far into the ocean, till at low water the sea and land seem to melt into one. In another spot, as at Beachy Head, the dizzy cliffs seem to plunge at once sheer (Fig. 1) into the ocean depths. In one locality the blue waters run up in little creeks and bays far into the land; in another, a grassy point, marked by its whitewashed lighthouse, juts out into the waves. Here the cultivated fields overhang the water's edge; there the shore-line is fringed by the long dunes of blown sand that guard the grassy "links" loved by the leisurely golfer.

Fig. 1.—Beachy Head

To the mere searcher after the picturesque, perhaps the most patent character of the familiar sights of the shore is their unchangeableness. In quiet weather how well-defined seems to be the boundary between the land and sea. The daily pulsation of the tide steals merely a narrow fringe of beach, which the land ever regains at the ebb. The long billows that break on the beach with a noise like thunder, scarcely disturb the incoherent sands below them,

or at most, leave merely a picturesque pattern of minute wavelets on the sandy floor. The heaving rollers that cover the sides of the cliffs with a veil of fleecy foam, rise and fall aimlessly and ineffectually.

But let him venture out when a wild north-easter is blowing, when the fierce gale lashes the waves till the sea is a chaotic mass of tumultuous billows, almost buried from sight in the clouds of hissing foam. If he can bear the brunt of the weather, he will see that the waves no longer keep the bounds that restrained them when the day was calm. Driven onward by the mad blast, they hurl themselves in wild disorder upon the beach. Mounting up the shelving shallows, they reach up to the sandy dunes, tear them away piecemeal and hurry them out to sea. The strong breakwater, built of gigantic blocks, seemingly hard as the hardest iron, cemented and clamped together into a solid mass, trembles from end to end under each thud of the ponderous billows, and the heaviest block that is broken loose is hurled aloft as if it were a feather. The sloping "talus" of rounded fragments that guarded the face of the neighbouring cliff is now covered by the breakers, and the loose stones are uplifted and dashed against the naked face of the cliff with the noise of artillery.

Now, for the first time, he begins to realise the fact that he is looking upon a mighty contest—the battle between the sea and land—one of which the ultimate issue can hardly be doubtful. It is impossible that any cliff, any shore, can endure such a terrible assault as this for ever; and this assault must of necessity be renewed at every gale. The fragments of rock these billows loosen and pound together are the visible proofs of the sure and certain dissolution of the edge of the land.

The coast of Britain affords everywhere abundant proofs of the destructive nature of these repeated attacks. The whole eastern coast-line of England is being cut away by the waves at the rate of from two to four yards in the course of the year. The old sites of the ancient ports of Ravenspur, Cromer, and Dunchurch, are now buried far beneath the waters of the North Sea. At Weybourne, in Suffolk, there is now water enough to float a frigate where, not many years since, a village stood upon a cliff fifty feet high. The southern coast is being cut away almost as rapidly, and the waters are aided in their work of destruction by the frequent landslips that bring the shattered rocks within reach of the billows. The site of old Chichester and its ancient cathedral is now far out at sea. Year by year the paths of the coast-guardsmen retreat inland before the advance of the waters.

Nowhere in Britain is the violence of this perpetual onslaught, and the swift and certain advance of the sea, more clearly exhibited than on the extreme north coast of Scotland, and the outlying islands of the Orkneys and Shetlands. In many localities in these wild regions, even on the calmest day, the tide runs with such swiftness that the sea-line is white with spray. In the fierce gales that sweep in from the wide ocean to the west, the spectacle is sublime and terrific. The tumultuous billows of the Atlantic, arrested by the land, pile themselves one over the other, and hurl their united waters in solid sheets up the faces of the perpendicular cliffs to the height of more than a hundred feet. Driven onward by the tempestuous wind, which tears fragments of stone from the faces of the precipices and flings them far and wide over the pastures, the waves dash themselves up the narrow voes and creeks with which these coasts are pierced. So great is their force that they rend off sheets of strata from the living rock, and pile them in heaps at the shoreward end of the creek, like the *débris* of enormous quarries. The effects produced in these regions by the combined action of the wind and waves are almost incredible. Dr. Hibbert describes solid masses of rock, containing from 200 to 300 cubic feet, as being lifted from their native beds by the waves, hurled to distances of from 30 to 90 feet, and ultimately shivered into fragments. The well-known "Grind of the Navir" is a mighty chasm which has in this manner been hollowed out of solid porphyritic rock within the memory of man. Every little seam of softer rock is at once eaten into by the waves and rapidly scooped out, first into a cavernous hollow, up which the sea washes with the noise of thunder, and finally into a narrow "voe," dark with its overhanging cliffs.

The coast scenery of these northern islands, more especially where they are composed of the old red sandstone, is wonderfully striking and picturesque. Towards the Atlantic face perpendicular cliffs, from five hundred to a thousand feet in height, their bases ever bathed in a long line of white foam, and their upper edges fretted into countless stacks and pinnacles of rock in every stage of formation and decay. Tinted with bright hues of red and yellow, their sides ribbed with the horizontal lines of rock-stratification and scored by innumerable joints, they rise up majestically into the air, the

silent, but awe-inspiring witnesses of the irresistible might of the ocean.

The unique character of this coast scenery is the natural outcome of the physical fact that the strata out of which these cliffs are carved are slightly-sloping beds of alternate sandstones and shales, traversed by countless joints and cracks. The waves penetrate into these weaker portions, and loosen the rock in cubical slabs. These are soon washed off, and the cliff falls away in great vertical slices, thus preserving its striking perpendicularity. Where these vulnerable spots are more than usually abundant the cliff is cut down to the sea-level in vertical chasms, and giant square-sided stalks are cut off from the mainland, and stand isolated, like colossal chimney-stalks of dizzy altitude. The most remarkable of these is the Old Man of Hoy, a vast square-sided column of coloured sandstone six hundred feet in height, and a well-known landmark to the mariners of these storm-vexed shores.

But it is not only the sandstone rocks which suffer from the ravages of the ocean on these islands. Their peculiar arrangement of bedding and jointing allows the waves to act with greater rapidity; but, in truth, nothing is proof against the attack of the waters. The hard mica-schist, the indurated quartz-rock, and even the intractable granite, waste in their turn, each with its own special form of weathering. The larger islands are slowly broken up; the small ones melt down into mere clusters of fantastic rock-pillars, which, rising here and there far out at sea, are likened by the fanciful mariner to the pipes of an organ or a fleet of ships in full sail.

Wherever the coasts of the British Islands are exposed to the full sweep of the Atlantic waves, the rapid devouring of the shore is especially noticeable, and the scenery approximates somewhat to that of the Orkneys and Shetlands. The west coasts of Scotland and Ireland are gashed to a jagged outline throughout. The narrow creeks, the steep cliffs, the rocky islets, return upon us again and again in endless succession, but varied and modified by the ever-changing nature of the rocky block which the ocean carves.

He who rambles along the margin of such iron-bound shores as those just mentioned, when the tide is low, cautiously picking his way over the projecting ridges, and coasting the numberless little creeks and pools, can hardly help asking himself why the waves do their work so capriciously. Why does this long ridge of black rock, almost buried from sight at its outer end by its mat of barnacles, rise so much above the general surface, running like a squat wall far out to sea? This little creek, running far back into the land, never quite empty of the sea-waters, and fringed with its growth of bladdery weed that rises and falls rhythmically with the motion of the waves, why is it here? The answers to these questions are not far to seek. Let the observer examine the rocks before him, tapping them with his hammer. He will discover for himself, in the course of a few minutes, that the rock of which the projecting reef is composed is far harder than the strata around it; or it is solid and compact, formed of a single bed, while they are jointed, thin-bedded, or shaley. Its present prominence is due to the simple fact that the waves found it more difficult to erode it than they did to wear down the surrounding beds; and its prominence with respect to these will be found to be pretty much in direct proportion to the amount of the sum total of its resistance to aqueous erosion, as compared with the general average of the rocks around.

The little bays and pools will be found to owe their origin to the same cause. A softer set of beds, a group of thin-bedded shales, a more jointed assemblage of sandstone—anything, in fact, that allowed the waves to act with greater rapidity will be found to have been the prime cause of the commencement of the depression, which is daily widened at the expense of the harder rocks which bound it.

If he now study a geological map of Britain, he will see for himself that he has in this simple manner discovered the cause of the vast majority of the repeated changes in the coast-line. The capes and promontories are, as a rule, formed of the harder rocks; the bays and inlets are eroded in the softer material.

The hard "basset," or upturned edge of the well-known chalk formation, runs diagonally through England from Dorset to Yorkshire. Where it strikes the southern shore we find the promontory and cliffs of St. Alban's Head, and where it touches the German Ocean on the Yorkshire coast we find the headland and cliffs of Flamborough. Where its inlying edge that surrounds the Weald comes upon the Straits of Dover, we find the dizzy mass of Shakespeare's Cliff (Fig. 2); where it strikes the Channel is the bold foreland of Beachy Head. The durability of the harder chalk is apparently the only cause that has preserved the Isle of Wight from destruction. It forms the rocky backbone of the island, and runs out to sea in the picturesque stack of the Needles.

Fig. 2.—Shakespeare's Cliff.

their existence to the fact that they are composed of the hardest rocks in Britain. The promontory of Cornwall would long since have been buried beneath the waters of the Atlantic but for the fact that it is a land of granite and intractable metamorphic rocks, upon which the sea has comparatively little power.

In obedience to precisely the same general law, the bays and inlets are worn out of the softer strata. The shallow inlet of the Solway Firth is cut in the clays and sandstones of the poikilitic and lias. The long inlet of the Bristol Channel has been plainly hewn out of a long basin of soft secondary rocks that once lay between the hard sandstone ranges of South Wales and Devonshire. The straits of Spithead and the Solent have been washed out of the soft sands and clays of the tertiaries, and so also has the long estuary of the Thames itself. The Wash and the Humber are cut out of the soft oolites that lie within the escarpment of the chalk. The estuaries of the Forth and Clyde have been carved out of the soft beds of the higher carboniferous. Countless other instances might be adduced. Every indentation and projection of the coast-line is an unmistakable monument of countless ages of erosion.

This erosion, so powerful in its ultimate effects, is not carried on in every locality at a corresponding rate; and, indeed, anyone who is at all familiar with coast scenery is almost certain to arrive at the conclusion that only a very small fraction of the shore is being cut away. Every fragment that falls from the cliff eroded by the waves is at once carried away, and the denudation is evident; but between every headland in Britain are countless little bays with soft beaches, that

Let the reader who feels this difficulty, visit some little bay small enough to bring all the phenomena before his eyes in a single view. At either end of the bay are the two steep cliffs that overhang the deeper water, and against which the waves dash their fiercest. He will soon see that each long wave as it comes in from the sea breaks its original force against these cliffs, and that the parts of it which enter the bay itself have their speed arrested. Their motion decreases in the shallowing water, and dies wholly away at the landward margin of the bay. A few minutes' observation will enable him to perceive that the form of the bay is almost precisely that given by the bounding headlands to the entering wave. Remove the headlands, and the waves would begin to destroy the beach; alter the form of the entering waves, and they will rapidly cut the soft shore-line to their new shape.

Where, as in the English Channel generally, the waves strike the shore obliquely, a new set of phenomena make their appearance. At each advance of the wave it lifts forward the sand and shingle obliquely up the beach. On its retreat they roll back into the sea, not along the line the wave impelled them, but perpendicularly to the shore-line, under the force of gravity. In this way they are gradually driven forward along the coast-line, and are gradually worn down as they proceed—their places being continually filled by fresh material. To protect the easily eroded coast-line, the dwellers in these parts drive rows of piles into the beach. These piles, or groins, as they are called, arrest for a time the advance of the pebbles, but the sea soon piles them up to the height of the groin, forms a new beach a little more distant from the land, and the travelling of the stones goes on as before. The island of Portland is such a groin, which has been formed by nature itself. The travelling beach behind it is the well-known Chesil Bank, which protects the coast of Dorset. The erosion of the island itself goes on with wonderful rapidity. When it is wholly cut away, the Chesil Bank (Fig. 3) will

disappear, and the Dorset coast be again given over to the fury of the waves.

Along the coast of Britain generally, the set of the currents is usually along shore, and the *débris* worn from the cliffs or brought down by the rivers is carried out to sea to the sandbanks of the Goodwins, the Dogger, and the like. In spots sheltered from the action of these currents there is an accumulation of sandy matter, and the land for a time seems to gain upon the sea. Of this nature are the "links" of our northern districts, protected by their dunes of sand. The formation of these peculiar hillocks is very simple (Fig. 4). When the tide is out and the wind is blowing off the sea, the dry sand is lifted by the gale a few inches above the level of the ground. The bushes and bunches of grass that fringe the land untouched by the waves are sufficient to arrest the advance of the sand, which falls in little mounds along that line. Every gust pushes forward a little more sand, which is forced to the summit of the long ridge of heaps, and falling over rolls down on the opposite side. In this way a long mound of dunes is formed parallel with the shore, having its height proportioned to the average strength of the local gales. Within it, towards the land, are the "links" themselves, ridged with the broken-down relics of former dunes, in one spot verdant with short sweet turf, in another ablaze with golden gorse.

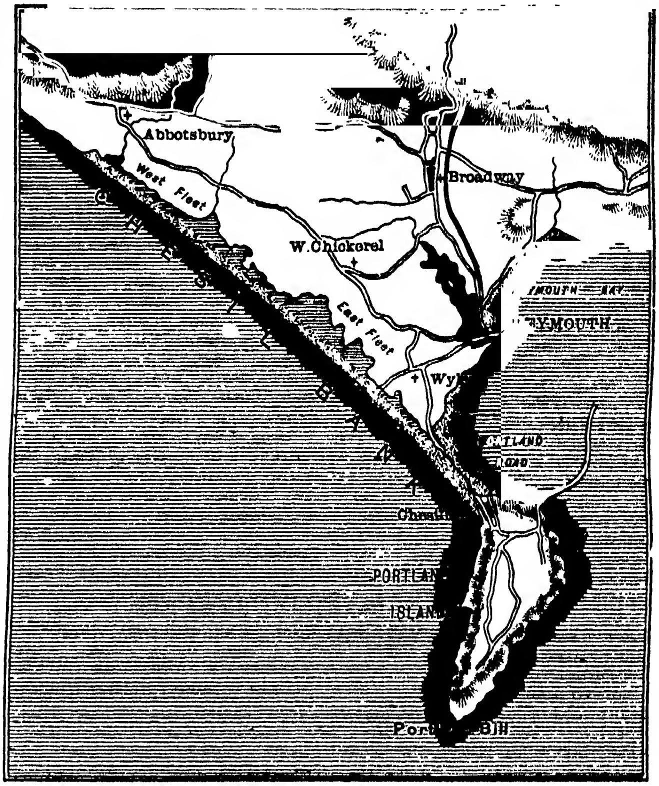


Fig. 3.—Map of the Chesil Bank and Neighbourhood.

But, like the sandy beaches, these long stretches of blown sand accumulate only in the sheltered spots, protected by the configuration of the neighbouring coasts from the full force of the ocean current. They derive their materials mainly from the waste of the outlying cliffs where the real work of degradation is incessant. Let us return to these, and see how this work is being carried on.

Fig. 4.—Formation of Hills of Blown Sand (Dunes).
(a) Bushes, fence, or other obstacle to onward progress of drifting sand. The arrows indicate the direction of the wind drifting dry sand from the beach.

When the tide is at its fullest, the cliffs are fringed by a wide stretch of white breakers, running for some distance out to sea. When the tide is low this coast-fringe is exposed, and is seen to be a wide rocky platform stretching outward from the base of the cliffs (Fig. 5). As we pick our way painfully over its rugged floor we behold everywhere the proofs that this platform is in reality the work of the waves. The base of the cliffs is smoothed by the stones that have been hurled against it, and is worn out into overhanging hollows and deep dank caves. On the floor of the platform itself the might of the waves is quite as plain. Its surface is worn into countless heights and hollows, and its seaward edge into a multitude of small creeks and promontories. Little thought is needed to perceive that this platform has been cut bodily out of the cliffs themselves, which must once have stretched seaward to its outermost edge.

This sea-worn platform is met with wherever the coast is being eroded with more than ordinary rapidity, running like a wide selvage along the edge of the land. It is very strongly marked on the east coast of Scotland, on the iron-bound shores of

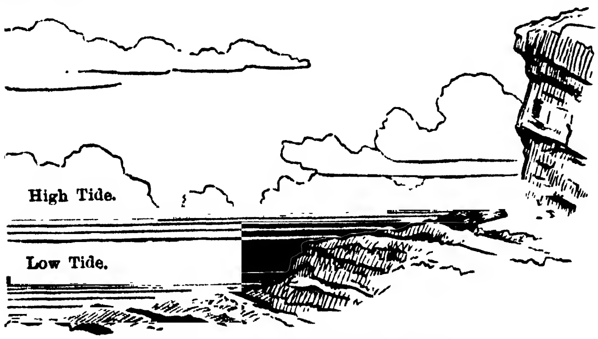


Fig. 5.—Sea-terraces or Coast Platforms.

Fife and Forfar. Nor is its origin far to seek. In the open sea the waters simply rise and fall in successive undulations. It is only in shallows or when obstructed by the edge of the land that these undulations become waves of translation, and press forward the loose material that lies in front of them. Even this power is restricted to a few feet of the surface of the waters. It ceases at a very moderate depth; and it is very doubtful if the forward movement of the waters a few feet below the surface is sufficient to impel stones and boulders over the bottom with sufficient force to erode the sea-floor. The distance at which the waves cease to act effectually is gauged with tolerable accuracy by the depth of these coast-platforms. Sometimes several of these platforms are bared at the lowest tides, rising like a series of terraces in successive steps towards the shore. The deepest shelf has plainly been cut out by the waves of the lowest neap-tides, the highest platform by the spring-tides in spring weather, and the intermediate steps by intermediate tides (Fig. 6.) In all cases the method and results are precisely similar. The shoreward edge of the water cuts its way in a horizontal groove landward into the cliffs, the unsupported rocks above fall into the waters, there to be pounded to fragments and hurried off by the currents into the deeper hollows. The seaward edge of the land is thus rapidly worn down to a tolerably uniform level, and the rock-bound coast is fringed by a broad and slightly sloping platform running far out to sea.

The coast scenery of the shores of Scotland is frequently marked by a peculiarity, rarely discernible in that of the southern parts of Britain. In many districts the line of cliffs appears for a time to retreat from the actual shore-line, running back into the body of the land, and leaving a broad margin of level ground, often many miles in width, between it and the beach (Fig. 7.) This flat ground—the "Carse-land" of the Scots—is, as a rule, highly fertile, and forms perhaps the best arable land in the country. Its resemblance to an old sea-platform, like those we have been describing, is apparent to the most superficial observer. On a first examination, however, this view of its origin appears untenable, for it is soon apparent that its general surface is several feet above the level of the highest spring-tides; but an extended examination places it beyond question that these inland cliffs must at one time have been reached by the sea-waves. We soon recognise in them all the features of the true sea-cliff—the overhanging precipice; the frequent cavern, now scarcely visible through the veil of tangled bushes and weeds that hides the entrance; the little creek, where the rocks are soft, now green with short sweet herbage; the old reef, where the rocks are hard, rising out bare and grey through the brown

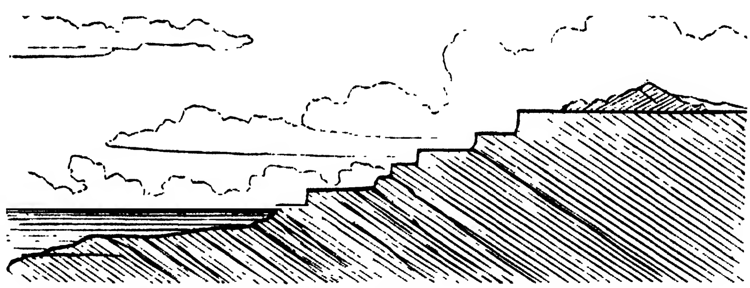


Fig. 6.—Sea-terraces or Tide-lines on the West Coast of Ireland. (*After Kinahan.*)

soil of the corn-field. When, finally, we pick up an abundance of half-destroyed sea-shells in the grass-grown sand that fills the crevices of these old sea-cliffs, our conviction becomes a certainty. There is no escape from the conclusion that we are looking upon an ancient shore-platform, now raised high and dry above the reach of the waves.

One such solid platform, the surface of which is now about 25 feet above the level of the ocean, can be traced almost continuously round the coast of Scotland. On the east coast it forms the floor of the fertile carses of Falkirk and Gowrie; on the west coast its relics are apparent in nearly every

sheltered bay. From about 120 feet above the sea-level down to its present average position, we find these terraces at various heights. For this phenomenon it is clear there can be but one explanation: the island of Britain must have been elevated again and again, and these successive platforms must have been the work of the sea-waves during the successive pauses in the general upheaval.

But if upheaval of the land has actually taken place, analogy would lead us to suspect that there may also have been depression. Though the proofs of depression are not so patent to the ordinary observer as those of upheaval, they are fully as conclusive. In many districts where our shores are shelving—as near the mouths of the Tay, the Humber, and the Severn—after a more than ordinarily tempestuous day we see quantities of peaty-looking matter cast up by the sea, and the entire beach blackened with its triturated fragments. If we examine any of the larger pieces of this black-looking matter, we find that it is made up of dark clay, filled with peat, pieces of wood, mosses, equisetums, and the like—the characteristic vegetation of cold moist ground. This is washed up by the sea from old forest beds, now submerged below the level of the waters. In excavations for docks and bridges, these ancient floors are cut into by the workmen. Everywhere we find them to be composed of some thickness of peaty matter, in which lie the prostrate trunks of the oak, the fir, and our common forest trees, the old roots of the monarchs of the forest still in place; and, scattered on the old forest floor, lie the acorns and the hazel-nuts that dropped from the trees of the wood in its prime, and the sub-fossil antlers of the deer and elk that roamed the forest glades. The whole is usually buried under a much later accumulation of sand and clay, full of our commonest sea-shells, laid down by the sea-waters that have overspread the site of the old forest since its submergence.

Fig. 7.—Old Sea-terrace or raised Beach.

Of the extent of these repeated upheavals and subsidences we can as yet form no adequate idea. The total variation of level in this part of the world, even since the advent of man in these regions, probably amounts to several hundreds of feet. The fragile shells of the common shell-fish of our present coasts may be collected unbroken from the old sea-beaches of Moel Tryfaem, high up on the flank of Snowdon; and peat, turf, and the stumps of the forest trees of forgotten lands may be dredged from the centre of the German Ocean.

In this way, by repeated upheavals and subsidences, every portion of the earth's surface is brought for a time within the narrow zone where, as we have seen, the shore-waves pare it down to their average level. Every part of the land surface, and, in all probability, every part of the sea-floor, becomes in its turn the shore-line, and is subjected to the wear and tear of the waves of "the wild and wasteful ocean." When there is a lengthened pause in the general movement of the earth-crust in any region, then the waves have time to cut a fringing platform. The width of the platform recognisable around our coasts affords us some idea of the length of the present pause in the general movement of the earth-crust in these regions. The carse platforms of the northern coasts mark former pauses, when the land stood much lower, relatively to the sea-level, than it does now. These elevated terraces have, probably, their counterparts below the present level of the sea. They are, however, not only invisible to us because of the superincumbent waters, but are hardly to be detected even by the most careful soundings. This is inevitable, for the inequalities of the sea-floor are being continually smoothed away by the deposition of sediment from rivers and from the waste of the cliffs, which is distributed by the sea-currents into all the deeper hollows.

But these pauses in the movement of the earth-crust are, most probably, rather the exception than the rule. *In a continued movement of upheaval or depression there would be no time for these terraces to form. Again*, though a terrace might appear to be permanent during any period of movement, as the land rose or sank gradually, if the movement were sufficiently slow the terrace would rise and fall with the movement of the land, the waves cutting down and lowering the old terrace as the land rose, or cutting forward and upwards continuously as the land sank. All these causes tend to give a gradual slope to the sea-bed, and would lead us to expect a gradual deepening of the sea in proportion to the distance from land. This, indeed, we find to be the case; to such an extent that the floor of the sea is to all appearance a continuation of that of the land; where the slope of the latter is small the sea is shallow, where the land-slope is steep the water deepens rapidly.

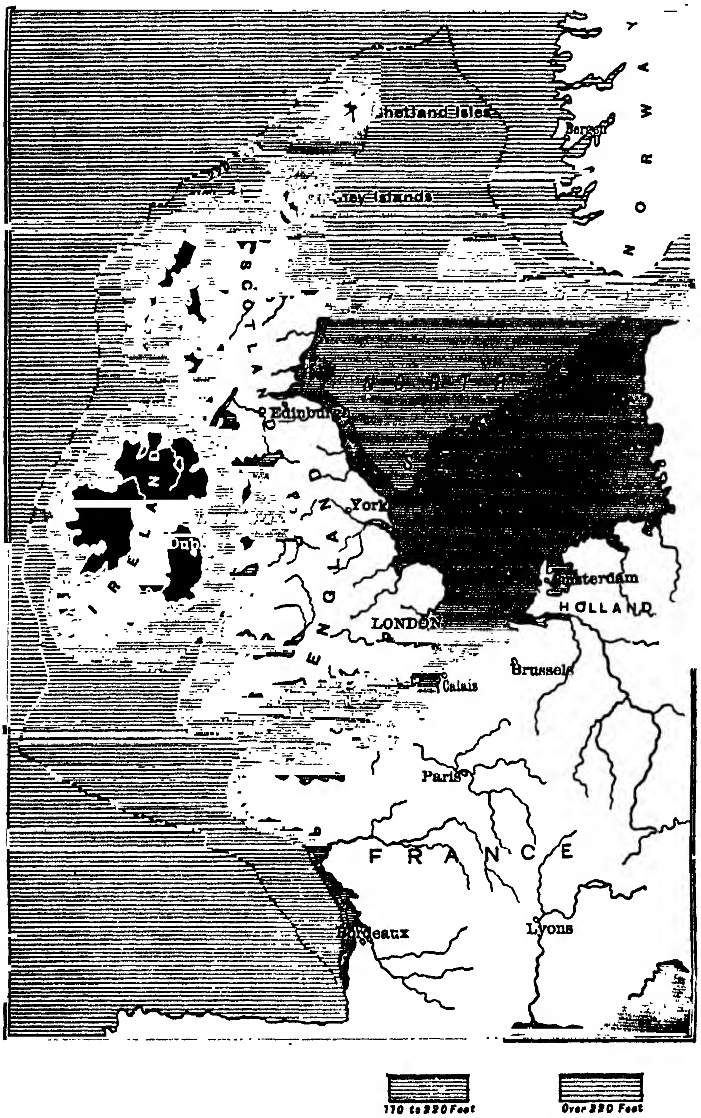


Fig. 8.—Map showing the Principal Lines of Soundings round the British Isles.

If we study a good chart of the coasts of Britain, we shall find that, as a rule, the present coast-platforms stretch out to sea no farther than the line where, on a stormy day, the white breakers begin to form. The floor of the sea beyond this line is below the depth at which the waves have any power in moving foreign matter with sufficient force to erode it (Fig. 8). A wide fringe of shallow water surrounds these islands, marking the places where the rock has been worn away when the land was higher. Beyond this the waters gradually deepen—nowhere, however, to any great depth on the eastern and southern coasts. An elevation of a couple of hundred feet would leave dry all the floor of the German Ocean and English Channel, and unite these islands to the Continent. This elevation, as we have seen, has probably more than once taken place, for it can be paralleled by the depressions we are able to demonstrate.

If these elevations have occurred, we can at once account for the presence of those shallow arms of the sea that separate us from the Continent. They must have been cut by the shore-waves during the gradual rising of the land, and the *débris* flung over the deeper parts of the ocean. They are very shallow. The deepest point of the strait between Folkestone and Calais is about 150 feet; an elevation to half that extent would again bring a large proportion of the surface within the erosive powers of the sea-waves. Its shallowness may be imagined from the fact that on a profile section of the Strait of Dover, 65 feet in length, this extreme depth would be represented by a depression of only one inch.

On a comparison of the geological maps of the opposite coasts of England and France, the suspicion that these water-filled depressions which divide them are the result of erosion becomes greatly strengthened. The long oval of the wealden formation that stretches through Sussex into Hants, and is cut through by the coast of the English Channel, is seen to be continued and completed on the opposite coast of France. The "basset" or outcropping edges of the chalk which form the North and South Downs of England find their continuation precisely opposite, and in the same general relations on the French shores. Outside them, precisely as in England, lie the tertiaries. The two countries have clearly been carved out of a single geological block. The waters that now form the English Channel and the Strait of Dover flow in a very shallow groove, worn on the upper face of this block, the strata of which it is composed being continuous from shore to shore under the shallow waters.

The grand idea which this conception gives us of the power of the sea during long-continued periods of time, dwindles into nothingness beside the tremendous amount of erosion that the ocean has effected around the British Islands. A study of the soundings around the coasts of these islands shows that they stand upon an elevated platform connected with the continent of Europe, with a submerged surface everywhere less than 200 feet below the present level of the sea. Outside the line of 220 feet, as shown on the accompanying sketch-map (Fig. 8), the water deepens rapidly to a depth of several thousands of feet. These deep waters thus surround a giant sea-terrace, stretching out from the shores of Europe into the Atlantic Ocean. Out of the waters which now bathe this terrace rises the swarm of islands and islets of Great Britain—like the reefs and skerries that jut through the waves on a coast-platform at highest tide. It has all the appearance of an old peninsula, which, like that of Spain and Portugal of the present day, once formed an integral part of the European Continent. The waves of the wild Atlantic working ceaselessly for untold æons, aided by many an elevation and depression, have shorn it into a sloping ocean platform, out of whose covering waters rise the worn and wasted fragments that form our native isles.

THE SUN TELEGRAPH.

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COMMUNICATION between places separated by distances more or less considerable, and by means other than electric telegraphs, is no new thing. Beacon-fires by night, smoke-signals by day, connected series of semaphores with movable arms, have long been used for the transmission of information according to certain pre-arranged and definite systems or codes. But of late years signalling in the army has been more carefully studied and systematised, though the employment of sun-light as a means of transmitting messages has effected no alteration in the principles on which such transmission is based.

It will be well, therefore, to examine first the different methods adopted, under the various conditions of service, for telegraphing from one point to another, and the way in which messages so sent are read and tabulated. Visual signalling has the great advantage of being accurate, and requiring few appliances. It can, therefore, be employed where the electric telegraph could not be laid down or does not exist. It depends, primarily, on the translation of the letters of the alphabet into certain telegraphic symbols. These are composed of combinations of dots and dashes representing the several letters, or certain set phrases, similar to those in use by the ordinary electric telegraph when printed or impressed by the machine itself. The translated alphabet used is that of Morse, and the letters and numbers are expressed as follows:—

Letters.

A	- —	N	— -
B	— - - -	O	— — —
C	— - — -	P	- — — -
D	— - -	Q	— — - —
E	-	R	- — -
F	- - — -	S	- - -
G	— — -	T	—
H	- - - -	U	- - —
I	- -	V	- - - —
J	- — — —	W	- — —
K	— - —	X	— - - —
L	- — - -	Y	— - — —
M	— —	Z	— — - -

NUMBERS.

1 -	6 —
2 - -	7 - —
3 - - -	8 — -
4 - - - -	9 - - —
5 - - - - -	10 — - -

In military telegraphy numbers are often of considerable importance, and are always spelt. But in addition to these are the set signals, by which the telegraphist can signify certain necessary facts without going through the trouble of actually spelling them word by word, or letter by letter. The most common ones are—

Preparative.	Expressed by	- - - - - - - - - - -	&c.
Stop	,,	— — — — —	&c.
General Answer (or understood)	,,	- - — - — -	&c.
Station sign	,,	- — - - -	
Repeat	,,	- - — — - -	
Cipher	,,	— - - - - - — -	
Comma	,,	- — - — - —	
Full Stop	,,	- - - - - -	

These conventional signs are not difficult to learn, but in order to facilitate their committal to memory, Mr. S. Goode has suggested their tabulation in the following manner. It will be seen that the signals are arranged in similar groups, the long and short dashes being inverted, and the extra combination (CH) is added for uniformity:—

GROUP I.

E -	T —
I - -	M — —
S - - -	O — — —
H - - - -	Ch — — — —

GROUP II.

A - —	N — -
W - — —	D — - -
T - — — —	B — - - -
U - - —	G — — -
V - - - —	

GROUP III.

L - — - -	Y — - — —
	C — - — -
P - — — -	X — - - —
V - - — -	Q — — - —
	Z — — - -
R - — -	K — - —

If a cipher message be required, the cryptograph or cipher wheel may be used, but this is difficult to explain without practice in its working. A similar plan is that advocated by Sir Garnet Wolseley in the "Soldier's Pocket Book." He divides a square into twenty-five spaces, numbered as here shown:—

1 M	2 A	3 J (I)	4 E	5 S
8 T	9 Y	10 B	11 C	6 D
7 F	12 G	H	12 K	7 L
6 N	11 O	10 P	9 Q	8 R
5 U	4 V	3 W	2 X	1 Z

beginning at the left top corner, and proceeding along the top and down the right side, and then again beginning with 1, along the bottom and up the left side, and so on along the top again. Then a key-word is chosen, as for example "majesty," and the letters composing it are entered in the squares from left to right until the word is complete. After the last letter of the word the alphabet is begun, but if the first letter (A) be in the key-word, as in this instance, the next letter (B) is entered, and so on to C and D, the letter E being omitted again, because it appears in the key-word. It will be seen, therefore, that for every number there are two squares, 1 representing both M and Z for example. To send a message, replace the original letters by others, which stand in squares bearing a corresponding number. Thus, if the message began with M, in square 1, the corresponding letter would be Z, also in a square numbered 1.

The transposition of "Science for All" in the above cryptogram would be UOWVDOVLCTXFF. And in sending a cipher message it is customary not to make any division between the words as in ordinary cases.

The transmission of a message by any system of visual signalling would be conducted in this manner:—The two stations have each assigned to them a letter called the "station sign." The first step, then, is to call the attention of the party at the required point, which for illustration may be called B, the first station being A:—

A signals - — - - - (station sign) — - - - (B).
B replies — - — - — - — - — - (Understood).
A signals - - - — - - - - - - — - — - - - - (Science).
B replies after each letter, and at the conclusion of the word — - — - — - — - (Understood).
A signals - - — - — — — - — - (for).

B replies as before.

A signals . —   . — . .   . — . .   (All).

B sends back the "general answer," or "understood," and the communication ceases.

The expression of the letters of the alphabet by lines and dots can be effected in many ways. Sound can be employed, as in long and short blasts of a steam-whistle, a bugle, or even a fog-signal. Long and short jets of steam could also be used. But the common methods adopted are those in which the signals are made by flags or by mechanical

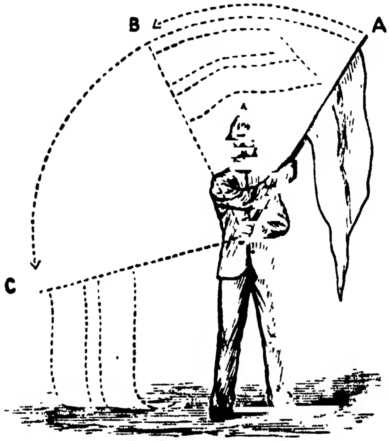

Fig. 1.—Flag Signals.
AB, BA, represents a Dot: AC CA, represents a Dash.

apparatus, the movements of which correspond to the presence or exposure of light and its temporary obscuration, on which the principle of the latest invention, the Heliograph, is based. Flag-signalling is based on the fact that flags are visible for some distance, but not fully so except when in motion. The operator, standing with feet apart. holds the flag, which is either all blue or white with a blue stripe, depending on the dark or light nature of the background, diagonally across the body to the left, with the right hand. The short or long dashes are then represented by a short movement of the flag to a diagonal position on the right, corresponding to the former position on the left, or by a longer movement, when the flag is lowered till it nearly touches the ground. In both cases the dash or dot is completed by the return of the flag to its original position, across the body to the left (Fig. 1). Flag-signalling may also be carried on by hoisting and dipping the flags on an ordinary ship's mast.

The Collapsing Drum (Fig. 2) is used chiefly for communication between ships and the shore, and is worked by hand. When closed it represents absence, and when extended presence of light. The amount of time during which it is exposed indicates a dash or a dot. The Collapsing Cone (Fig. 3) is worked in the same way, and has been used for boat service.

The Shutter Apparatus (Fig. 4) is of a similar character, and is used between permanent stations

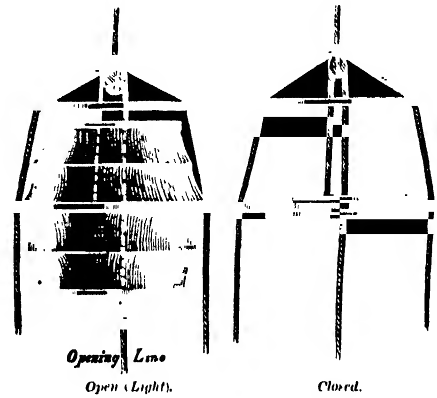

Fig. 2.—The Collapsing Drum.

on shore. The largest size has about seventy-two square feet of surface, and is visible for ten or fifteen miles in clear weather. As in the drum, the full exposure of the series of small shutters, each working on a pivot, which is effected by turning a handle connected by small levers with them, means the presence of light. When the shutters are moved into a horizontal position, as in Fig. 5,

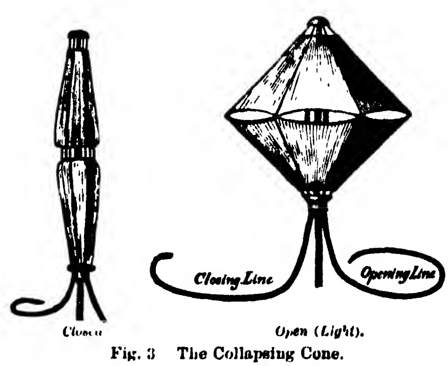

Fig. 3 The Collapsing Cone.

nothing can be seen at a short distance, as the frame and slips of wood are both very slight. This implies obscuration of light. If the background be dark, the frame should be painted black and the shutters white. If the background be light, as the sky, the converse takes place. At night common lanterns give very distinct signals, and the obscuration of the light is effected by means of a small screen, so pivoted as to be capable

of easy movement, which is interposed between the signaller and the observer. A good kerosene lamp is visible for ten miles, under favourable conditions, and good results have been attained by small portable hand-lamps of the commonest and simplest description. For very long distances, as in the triangulation of the Great Survey of England, limelight has been employed. In many countries, especially tropical ones, the nights are clearer and less hazy than the days, and telegraphic communication can be even more readily effected after dark than during the brighter daylight.

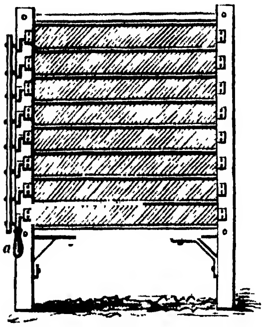

Fig. 4.—Shutter Apparatus.—Closed (Light), a, Handle.

But all these methods have disadvantages. The last-mentioned, for instance, is useless by day. The others are slow in application, limited in range, and often dependent on background, while in addition they are visible to every one, and where many signalling parties are engaged there is the possibility of confusion. Moreover, an intelligent enemy may, unless the message be in cipher, translate for himself the despatches that are being sent. Except the flags, too, all these methods are cumbrous and often bulky.

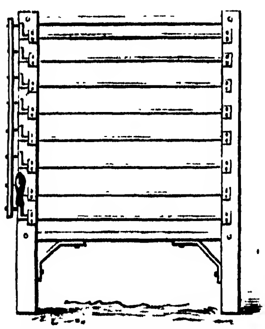

Fig. 5.—Shutter Apparatus.—Open.

The Heliostat or Heliograph obviates many of these difficulties. It is available equally by day or night, if there be sun or moon. It is very portable, very sure, has very great range, and further, is secret. The ray of light reflected by its mirror is directed on one point only, and is visible from nowhere else.

The principle of using a reflecting mirror is neither new nor confined to civilised modern communities alone. Mr. Galton notes* that the North American Indians transmitted information to each other from a lofty hill range to points beyond adjacent forests by means of flashes from a piece of glass. The fleet in which Alexander the Great coasted the shores of the Persian Gulf was said to be directed in its course towards India by flash-signals from the shore.

The *Times* of July 11, 1853, states in its Crimean correspondent's letter that "a long train of provisions came into Sebastopol to-day, and the *mirror telegraph*, which works by flashes from a mound over the Belbeck, was exceedingly busy all the forenoon." This evidently indicates telegraphic communication by some form of sun-signalling.

But the actual construction of an instrument specially designed for such work is of comparatively late origin. First of all, the Heliograph must not be confounded with the Heliostat, though the names are often used indifferently. The latter is used on great surveys to fix the points of the greater triangulation of the area, and is merely a mirror which throws a flash steadily in a certain known direction, but which is provided with no means for obscuring the reflected ray. It has been in use by the Ordnance Survey of England for nearly fifty years. In the Cashmere survey it was used between points as much as 100 miles apart, and often when intervening clouds or haze shut out the view of the light from the observer, it could still be detected by the use of a powerful telescope. Of course this instrument could be easily used for signalling, but ordinarily is not fitted with the means for making regular and definite short or long flashes of light. The Heliograph in most general use is that of Mr. Henry Mance, of the Government Persian Gulf Telegraph Department; but an "improved" instrument has been constructed by Captain Begbie, of the Madras Engineers, and another very similar to his by M. Leseurre, in France.

They are all alike in principle, that is to say, the dash or dot is produced by a long or short exposure of the reflected ray. But in Mance's instrument, and in the "Field Heliograph"—the most portable form for field service—the obscuration of the ray is effected by moving the mirror itself; while in the two others the reflection is shut off from the distant observer by a screen interposed between him and the mirror. In the French Heliograph, moreover, this screen is like the Shutter apparatus before referred to, being constructed of thin slips of metal on pivots, which can all be turned together by a connecting rod and handle, so as either to expose or interrupt the ray of reflected light. The object of

* "Art of Travel;" Colonel Dodge ("Hunting Grounds of the Great West," pp. 367, 368) also describes this aboriginal Heliograph, by which the Indian chief directs from a distance the movements of his warriors.

this arrangement of the screen is to increase the rapidity with which the exposure or non-exposure of the ray can be made.

It will be seen at once, however, that, putting aside the many things that interfere with sun-signalling, or "heliography," such as clouds and haze, and strata of unequally-heated air, which produce irregular refraction, the single-mirror instrument is useless when signalling directly away from the sun. At early morning and towards sunset, moreover, the quarter of the horizon opposite the sun can receive only extremely feeble reflected light. Hence it is that in both the Begbie and Leseurre instruments a second, or "sun-mirror," is added, which can be turned in any direction, and which receives the sun's rays directly, and then reflects them back on the signalling mirror. In the Begbie apparatus this is supported on a separate tripod, as also is the screen interposed between the signalling mirror and the observer; but in the French instrument the sun-mirror is attached to the stand on which the signalling mirror is fixed, and a separate stand for it is not thought necessary.

It does not seem, from experiment, that the size of the mirror affects the size of the reflected image; but by increasing its dimensions greater intensity of light is produced, and therefore the reflected ray has greater penetrative power. For long distances, therefore, the size of the mirror is usually increased. One 3 inches square can signal to points 10 or 12 miles off; one of 4 inches, 15 to 20 miles, as a rule, and up to 40 miles in exceptionally clear weather.

The only difficulty in these methods of visual-signalling by sun-light, is to ensure that the pencil of light shall be thrown on the point where the opposite observer stands. How this is effected will best be understood by a description of the instruments themselves.

The Mance instrument, or "Field Heliograph," is shown in Fig. 6. It consists of a small $4\frac{1}{2}$ inch mirror, supported or pivoted in a light frame on a tripod stand. In the centre of the mirror a portion of the glass is left unsilvered, so that the signaller can look through it and direct its axis towards the required spot. In order to set it at the required angle, the mirror is fixed in a frame which admits of horizontal or lateral adjustment, by means of a tangent screw. Vertical movement is obtained by means of a steel rod, which passes through a nut in the top of the mirror, and which is also provided with a tangent screw; but it terminates in a sort of handle or key, which is kept in position, somewhat, by a spring. Thus when the handle is pressed down, movement is imparted to the mirror, and on withdrawing the pressure the spring restores the handle to its former position. About 10 yards in front of the signalling stand is placed a "lining-rod," having on it a sliding stud, and also a small cross-piece, with a stud in the centre. The former is for aligning the centre of

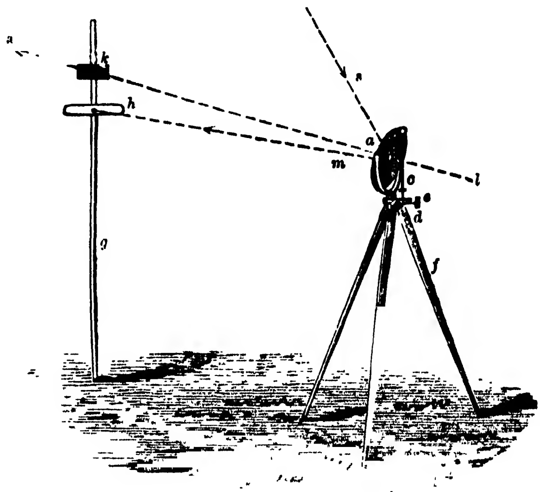

Fig. 6.—Mance's Field Heliograph.

(a) Mirror; (b) Sighting Hole, (c) Tangent Screw for vertical adjustment; (d) Key for deflecting the Mirror; (e Tangent Screw for horizontal adjustment; (f) Tripod; (g) Sighting Rod; (h) Cross-bar with Stud; (k) Sliding Stud or Sight; (s) Sun Ray; (mh) Reflected Ray at rest; (lkr) Direction of object.

the mirror with the object. The latter is intended to show if the reflected ray is wandering to the right or left of the true line.

A complete set of apparatus consists of two mirrors, a lining-rod, and separate cases to contain the mirrors and their frames. It is, therefore, possible to work in any direction, by utilising one of these as a "sun-mirror," to throw a reflection on the "signalling mirror."

The mode of operation is simple. The pressing back of the tangent screw, which imparts the horizontal movement to the glass, leaves the frame free to be moved by hand roughly into the required direction; and the operator then looks through the unsilvered part of the glass and aligns the sliding stud on the lining-rod with the distant station. This is first found by moving the mirror so as to throw a ray in the direction of the place, and waiting until the answering flash determines its exact position. The cross-bar on the lining-rod is adjusted at right angles to the rod about a foot below the sliding stud; or, rather, it should be so placed that the ray of light should rest on the stud in its centre when the instrument is not moved, and should rise to

and rest on the sliding stud when the key or handle is fully pressed down. Movement, for signalling, can now be given to the mirror by pressing the handle; and as the position of the sun alters, which would be shown by the ray passing to the right or left of the stud in the cross-bar of the lining-rod, a slight touch of the horizontal tangent screw will bring the ray back to the central position.

The disadvantage of this instrument is said to be that the movement of the handle, or key, disturbs the glass, and has a tendency to alter its position. This would especially be possible on sandy or soft sites.

The Begbie arrangement (Fig. 7) is designed to meet this difficulty. It consists of two mirrors and screens, each upon a tripod stand. Each mirror has a hole in the centre, in which can be fixed

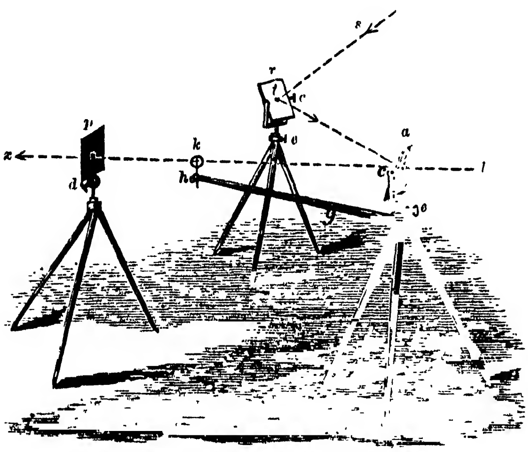

Fig. 7.—Begbie's Field Heliograph.

(a) Signalling Mirror; (b) Sighting Hole with white Disc; (c) Small-motion Screw for vertical adjustment; (d) Key, for signalling, on Screen (p); (e) Small-motion Screw on Tripod for horizontal adjustment; (f) Tripod; (g) Sighting-Bar clamped to Tripod; (h) Screw for clamping Cross-wire Frame; (k) Cross-wire Frame; (r) Sun Mirror; (t) Sighting-hole with black Disc, (p) Screen; (s) Sun ray; (lkx) Sighting-line and direction of reflected ray.

white or black "guiding discs" (the use of which will be seen hereafter), and has a slow-motion screw on its frame for vertical adjustments. Small horizontal adjustments are produced by a slow-motion screw at the head of the tripod. From the signalling mirror projects a horizontal bar, which can be moved in any direction, and clamped when in its proper line. At its extremity is a small circular frame, with cross-wires and a sighting-hole in the centre, which is fixed on a rod that moves up and down in a socket at the end of the bar, and which can be clamped by a screw. The sun-mirror is 5 inches, the other 4 inches square. Finally, the screen, which is in one piece, and unlike, therefore, the Venetian-blind sort of arrangement of Leseurre's instrument, is provided with a key, or handle, by which it can be made to obscure or expose the ray of light from the signalling mirror. Its position, therefore, is just in front of the cross-wire frame, and the reflected ray should fall on its centre.

Of course the machine can be worked like the Mance pattern, that is to say, when the position is favourable the sun-mirror can be dispensed with. In this latter case, then, the mode of operation is as follows:—While an assistant stands at the end of the bar to move it horizontally, or else raise or depress the wire frame as required, the observer looks through the hole in the mirror and aligns the centre of the cross-wires with the object. The arm and wire frame are then clamped, and a white disc is placed in the hole in the latter, and a dark one in the hole in the glass. The mirror is then unclamped at the tripod-head and moved till the ray of light rests near the sighting arrangement, and then being re-clamped, the small-motion screws are used to bring the reflection of the black disc of the mirror on to the white disc of the cross-wires. As, owing to the motion of the sun, the black disc shadow passes over the white one, it is brought back by the small-motion screws.

In using the second or sun-mirror, the tripod on which it is fixed is placed on one side of, and about a foot in front of, the signalling glass. After aligning the latter with the object, as before described, a white disc is placed both in the cross-wires and the signal mirror. Then looking through the hole in the sun-glass, the operator should alter the position of the other glass until the reflection of the hole in the cross-wires coincides with the white disc on it. Next, by the small-motion screws, the position of the sun-mirror should be altered, until the black disc, which now fills the hole in it, is reflected on the white disc in the other glass. Then the screen tripod is placed in position, and the signalling mirror should not be moved again, any alteration rendered necessary by the sun's movement being remedied by the sun-glass.

Though this obviates the possible disadvantage of moving the signalling glass itself, it has still disadvantages. First, the quantity of apparatus is greater, and the weight, 12 lbs., as compared with the 5 lbs. of a simple Mance instrument, is therefore greater. Next, it requires two operators to manipulate the signals—one at the screen, the other at the mirror. Lastly, the working of the screen through an arc of 90° takes a relatively longer time than moving the mirror itself through

2°; that is to say, the Begbie instrument is slower in operation than that introduced by Mance.

At Ekowe, in the campaign in Zululand, the whole apparatus had to be improvised, a common looking-glass belonging to one of the staff being utilised. The great difficulty experienced was in directing the flash on to the position occupied by the signalling party on the hills above the Tugela. A common gun-barrel resting on bags of "mealies" (Indian corn), and provided with brightened bullets for sights, was first tried, but it was not very successful. Then two wires with the

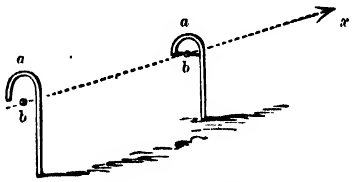

Fig. 8.—Lining-rods at Ekowe.
(a, a) Bent Wire; (b, b) Brightened Bullets; (x) Line of Sight to the Tugela.

upper parts bent into the form of a semi-circle, and with cross-wires uniting the bent end with the upright part, were tried. The sights were composed of brightened bullets in the centre of the cross-wires, and when these rods were set in the ground and aligned with the flash, no difficulty was experienced in communicating (Fig. 8).

In India, in some of the Cashmere surveys, the native assistants dispense with the sighting-rod, using only a piece of straight bamboo with a piece of cotton wound round it at the proper altitude. And there are many ways in which means of aligning the ray, which is the only practical difficulty, could be improvised.

Sun-signalling has great advantages over all other methods of visual telegraphy. Messages can be transmitted to great distances, and the clearness with which the signals can be made renders background of but little importance. In flag-signalling the distinctness of the signal depends materially on this question, and one of the first points that requires the operator's attention in this case is that he should place himself in the exact line in which he is going to telegraph, and then turning his back upon the distant station, notice against what materials his signals will be shown. On this depends his choice of the flag for the work. Unbroken backgrounds are better than more varied ones; thus trees and the sky would represent the darkest and lightest classes. And this kind of signalling can be most favourably carried out when there is a clear atmosphere and a clouded sun. Heliography, on the other hand, is naturally most effective on a clear day and with a bright sun. Given these conditions, there seems to be no practical limit to the distance over which a signal can be transmitted. The ray of sunlight is not lessened materially in intensity by reflection from the mirror's surface, for it is merely bent or altered in direction. But for great distances a considerable altitude for the signal station is essential, and this is not always obtainable under ordinary conditions of ground.

DEW AND HOAR-FROST.

By Robert James Mann, M.D., F.R.C.S., F.R.A.S., etc.,
Ex-President of the Meteorological Society.

Every one who has strolled over green pastures in the evening is aware that the grass becomes wet to the feet, when beaten and bare paths still continue dust-covered and dry, and when the atmosphere and sky above are without trace of mist or cloud. The dew which thus moistens the grass in the early evening is as old as the hills. It descended upon the sides of the snow-capped Hermon (Fig. 1) and upon the mountains of Zion three thousand years ago, when David followed his father's sheep at Bethlehem. The Greek philosopher Aristotle, more than twenty-two centuries ago, was aware that it was most generally present on clear and serene nights. It has been amongst the most familiar of the objects that have haunted the footsteps of men from the earliest days. Yet a short seventy years ago scarcely anything was known of its actual nature. Previously to that time it was regarded by some scientific authorities as being a result of fine rain precipitated from the higher regions of the air. By others it was held to be an emanation distilled out of the ground. The alchemists of the Middle Ages considered it an exudation from the stars. As recently as the year 1811, Dr. William Charles Wells, a physician of London, who afterwards managed to get the

first clear insight into the secrets of its birth, maintained that it was the parent, and not the offspring, of cold. It was in that memorable year, however, that the ingenious and successful experiments of this shrewd questioner of Nature began an effect of its presence. In the light of the clearer information which scientific men now possess, it is difficult to understand how there could ever have been any mistake upon this point, in the face of the familiar result, known at the time to every one,

Fig. 1.—Mount Hermon. (*From a Photograph by F. Mason Good.*)

to be made. Upon a certain lucky occasion, when he was staying in the country, having placed a thermometer on the grass when this was wet with dew, he noticed that it indicated a temperature eight degrees lower than another instrument suspended two feet above the ground. It was from this first observation he was ultimately led to the discovery that the greater cold of the lower position was the cause of the deposit of moisture upon the grass, instead of being, as he had previously conceived, that when a drinking-glass of cold water was brought into a warm room in the summer, the outside of the glass was immediately bedewed with trickling moisture. The deposit of water in this well-known case is manifestly an artificial manufacture of dew. In all essential particulars it is a quite similar process to the one which is practised by Nature when dew is formed on the grass. The only difference in the two occurrences is the way in which the cold that effects the precipitation of

the aqueous vapour is brought into play, and it was the instrumentality by which this cold was produced in the instance of the grass, which it was the good fortune of Dr. Wells to trace out and demonstrate by means of direct experiments carried on between the years 1812 and 1814.

The experiments of Dr. Wells were of a very simple and easily intelligible character, notwithstanding the important principle of meteorological science which they established. They were for the most part carried out through the instrumentality of small flocks of cotton-wool. He first weighed out this homely material into parcels of ten grains each, and he then "teased" and loosened out the fibres of each parcel until it assumed the form of a flat circular flock, exactly two inches in diameter. These flocks of identical weight and size were then exposed to the moist air in different ways and under varying conditions, and it was afterwards ascertained how much moisture had been deposited in any one of them during an entire night's exposure, by again weighing the flock in the scales. In his first experiments, he supported a painted board, one inch thick, four feet above the grass, upon slender wooden props, and then fixed one of his circular flocks of wool upon the top of the board looking up towards the sky, and another beneath the board looking down to the grass. The two flocks were thus only one inch apart, with the thickness of the board between them, and both were freely open to the air. After an exposure of an entire night in these circumstances, it was found that the flock on the top of the board looking up to the sky had gained 14 grains in weight from the moisture which it had imbibed, whilst the flock beneath, which looked towards the ground, only increased four grains in weight. In his next proceeding, he arranged two precisely similar flocks of wool, a little distance apart, upon the grass, and then sheltered one from the sky by a pent-house of card-board, whilst the other was left without any covering above. In this case, after a night's exposure, the uncovered flock had increased 16 grains in weight, whilst the one screened by the card-board had gained only two grains in weight. In order to make it quite sure that in this instance it was not rain which had fallen upon the uncovered wool to cause its increase of weight, he repeated the experiments in a modified form, by placing a circular cylinder of baked clay, 12 inches across, and 30 inches high, and open at the top, round one flock of wool, instead of covering it with the ridged pent-house. If rain were the cause of the load of moisture which the screened wool received it would clearly get to it on any still night through the roofless screen. But as a matter of fact, the flock included within the open circular wall only received 8 grains of moisture, whilst a companion flock upon the open grass received 16 grains. When one flock of wool was laid upon the open grass, whilst a second was placed close at hand upon a gravel walk, the wool upon the grass increased 16 grains, whilst the wool upon the gravel increased only 9 grains. Upon examining in connection with this experiment the actual temperature of the grass-plat and the gravel-walk, two and a half hours after sunset, it appeared that the gravel was sixteen degrees warmer than the grass. It was manifest, therefore, that the grass had shot off, or distributed, its heat into the air-space above much more rapidly than the gravel, and there could be no doubt that this was the proper interpretation of the deposit of the moisture upon the grass, and of its absence upon the gravel. The grass had become so chilled by the radiation of its heat, that it was capable of condensing upon itself the vapour that had been just before contained in the surrounding air. The fibres of cotton-wool do precisely the same thing. Indeed, it has been ascertained by direct trial that cotton-wool radiates its heat off into space one-fifth part more rapidly than grass, and that grass does the same thing four times more rapidly than gravel. In the first experiments of Dr. Wells, the pent-house of paste-board and the circular wall of baked clay each acted as a screen, and prevented the heat from escaping from the wool up into the air as speedily as it would have done without their intervention. It may thus then be accepted as scientifically proved that dew is simply the moisture abstracted from the air by the rapid cooling of the bodies with which that air is in contact. Dew is more readily formed on cloudy nights, because the clouds overhead then act as heat-screens, very much in the same way as the paste-board roof and the baked clay wall in Dr. Wells' experiments. It is not formed on windy nights, because the drifting air then brings its own temperature to the radiating bodies, and prevents them from getting cooled as speedily as they would otherwise do. Under all circumstances, dew forms upon some bodies, such as wool and grass, and not upon others, such as gravel and mould, because in the one case those bodies are good radiators of heat, and cool very quickly under an unscreened sky, whilst in the other case they are bad radiators, and cool very slowly, notwithstanding their free and open exposure.

sky. The mere drifting across of cloud-screens overhead immediately lessens the difference of temperature indicated in the two positions. Recording thermometers placed on the grass at night almost always give lower readings than similar instruments fixed upon walls, or on stands that raise them up a few feet into the air. As much as 20° of difference is not at all an uncommon one, and as much as 29° has been observed even in England. Very much more even than this sometimes occurs in hot, dry climates, where the surface radiation is very energetic at night. This process of ground-radiation explains the familiar fact that in England frost is so frequently indicated by thermometers placed on the grass, when there is not even a near approach to it in the air four or six feet above the ground. It also accounts for the well-known circumstance that delicate plants are often injured by frost, although nothing of the kind has been indicated by thermometers placed upon walls, or in high situations.

It is not possible to say how much water is thrown down upon the earth in a year in the form of dew. Some meteorologists have estimated the amount at five inches of vertical depth, or about a seventh part of the moisture which is evaporated into the air. Some recent experiments, very carefully made at Walton-on-Thames by Mr. George Dines, seem, on the other hand, to indicate that the dew scarcely amounts to more than an inch and a half of water in the year. The quantity of dew which is supplied to the earth in most places in England, very probably lies somewhere within the limits of these extremes. Whatever the exact quantity may be, it is, at any rate, enough to render very essential service in supporting vegetation through seasons of drought, when very little rain falls, and to justify the Hebrew Psalmist in speaking of it as a Heaven-sent blessing.

Fig. 3.—Landscape with Hoar-Frost.

The popular notion that a thick covering of snow protects vegetable structures contained in the earth beneath from the injurious effects of frost is entirely supported by the testimony both of principle and fact, notwithstanding the great radiating capacity of the external surface of snow which was referred to in speaking of the temperatures upon the Grand

Plateau of Mont Blanc. The depression of temperature from the effect of radiation is almost entirely restricted to the outer layer of the frozen deposit. The white porous mass which lies beneath contains as much as eight or ten times its own bulk of air mingled in with the frozen particles, and on that account is a very bad transmitter, or conductor, of the heat. None of the effect of the radiation is communicated through more than a very few inches of the snow, and the layers in contact with the earth are therefore commonly many degrees warmer than the layer in contact with the air. The snow-coat acts to the ground very much as the woollen "cosy" does to the teapot inclosed within its folds. It prevents it from dissipating its heat. The actual ground a few inches in, very rarely descends to the temperature of freezing water if it is covered over by deep snow. In snow-covered lands the mean temperature of the ground is commonly as much as 9° warmer than that of the air, and in some exceptional instances the ground has been found to be 40° warmer than the outer surface of the snow-covering.

The exceedingly beautiful appearance with which most of the inhabitants of England are familiar under the name of hoar-frost (Fig. 3) is nearly allied to dew. The white incrustation which at such times ornaments the landscape is, indeed, neither more nor less than frozen dew. It is dew deposited at a time when the dew-point of the air stands lower than the freezing-point of water, and when, therefore, the moisture which is abstracted from the air at once presents itself in the form of needles of ice. The ice spicules are arranged in a somewhat confused and indefinite way, on account of their intimate association with, and deposit upon, the surface of the radiating objects. The needles project from the frosted surfaces like the short, stiff hairs of a stubbly brush. They are most abundantly produced and most lengthened out wherever the radiation of heat is most energetically carried on, as it is at the points and sharp edges of serrated leaves, and each different kind of plant consequently has its own pattern of frosting. Hoar-frost is very rarely seen on smooth, rounded surfaces, and it never appears where radiation is prevented. Screens expanded above and around are, on this account, quite as effective in preventing the occurrence of hoar-frost on plants as they are in obviating the deposit of dew.

A FROG.

By Andrew Wilson, Ph.D., F.R.S.E., etc.

In a previous paper* we discussed the anatomy and physiology of that well-known animal the lobster, and we then endeavoured to show that within the compass of the economy of that familiar being, a considerable amount of natural history lore was contained and illustrated. It was also shown in the paper referred to, that the lobster might be made to serve as a type and representative of a large number of other animals, so that an acquaintance with its structure placed us in possession of trustworthy information concerning the general anatomy of creatures apparently differing widely from the crustacean in most respects. Insects, spiders, centipedes, and a host of other forms, possess bodies which are constructed on the same "fundamental type" as the lobster's frame; and a knowledge of the latter therefore served to convey to us the broad principles of structure as presented to view in that large natural group of animals named *Annulosa*, or *Articulata*. Now, in somewhat similar fashion that familiar creature the frog can be made, under zoological tuition, to convey to us the broad features of structure presented by the *Vertebrate*, or "back-boned" animals at large. Even man's own structure will be found to correspond in its broad lines and aspects with that of the frog; and given a facility of availing one's self of common sources of information, it may be shown that not a few points in human existence become clear to us from the study of a frog.

To describe the appearance and every-day aspect of frog-existence would be a superfluous task. The animal "sits" at ease very much as does a cat; and, indeed, exhibits also much of the stolidity of expression which characterises the familiar denizen of our hearths. In watching a frog in its resting posture, (Fig. 1), we perceive that it possesses characters which readily entitle it to rank as a member of the highest group, or sub-kingdom, of the animal world. Its limbs are thus found to be four in number, and to possess, as everybody knows,

* "Science for All," Vol. II., pp. 34—41.

like the body itself, an inner skeleton. In this respect, the frog agrees with man himself and with all other vertebrate animals; for in that group the limbs never exceed four, and are always in pairs—although, indeed, we may find no limbs at all, as in most snakes, or only one pair, as in whales and some by the case of lizards, serpents, and the like—are well provided in the matter of body-covering.

There is no distinct neck in our frog, the broad flattened head appearing to join the trunk directly and of itself. The eyes are very prominent; and although ears would, at first sight, appear to be

Fig. 1.—Frogs at Rest.

fishes. The frog's hind limbs are seen to be disproportionately long when compared with his fore members. These elongated limbs form very effective swimming-paddles, as might readily be supposed, and their five toes are duly webbed for natatory purposes. The front limbs possess four fingers only, and these fingers are destitute of a web. The frog is entirely unprotected by any hard covering. No scales are present, and in this respect, we may note in passing, it presents a very decided contrast to the reptiles, which—as may be readily illustrated wanting, the naturalist would point to a tightly-stretched surface of skin existing just behind the eye, and coloured of a dark hue. This is the *tympanum*, and represents the "drum" of the ear in higher forms of life; so that our frog's ear may be roughly compared to our own organ of hearing, *minus* the outer ear and also the passage leading from that outer ear to the "drum." There is no trace of a tail in the full-grown frog, albeit that in early life it certainly possesses an appendage of that kind, such an observation warning us that in studying an

animal form, it is necessary to become acquainted with its early history (or development) as well as with its later existence. The last feature of general interest in the outer aspect of frog-existence consists in a very noticeable prominence which appears in the animal's back, just where the haunch-bones and the spine are joined together. This prominence well-nigh gives the animal the appearance of being "broken-backed;" but if we glanced at the skeleton of the frog, as placed in a sitting posture, we should discern that the prominence in question was a perfectly natural and normal feature of its anatomy, and that it was due to the sharp angle formed by the union of the animal's haunch-bones with its spine.

So much for the external features of the frog. Beyond an occasional "wink" and a "croak"—which may be regarded as musical or not, according to the proclivities and tastes of the hearer—the frog, when at rest (Fig. 1), may be looked upon as the apotheosis of placidity. Breathing proceeds slowly and regularly in the animal, and, as we shall hereafter observe, is a process performed differently, in respect of its mechanism, from respiration in ourselves. When touched or irritated, the frog is given to the exhibition of discretion as the better part of valour. It nimbly leaps forward from the source of irritation, and if placed in the water swims with ease and agility. Impelled to eat by the claims of nutrition and the warnings of hunger, the frog captures its insect prey with dexterity. The tongue of the animal is attached, not to the back of the mouth as in higher animals, but to the front of the lower jaw, so that when a frog protrudes his tongue it is the free and forked hinder half of the organ which is seen, and with which the animal seizes the unwary insect—a work much aided by the glutinous secretion with which the tongue is covered.

The answer to the question, "What is a frog?" depends largely on a knowledge and understanding of its "development. About March in each year, as everybody knows, the frog's eggs are deposited in ponds and ditches. They form a jelly-like mass—not unlike a tapioca-pudding in appearance—in which the "yolks" of the eggs are apparent as specks of a black colour. The outer, or glutinous envelope of each egg swells to many times its original size, owing to its taking up a large amount of water; and hence a mass of frogs' eggs appears to cover a much larger space than is due to their original and normal size. The early changes noticed in the frog's egg are highly interesting, not merely because they show us the first beginnings in nature's manufacture of the living form, but because,

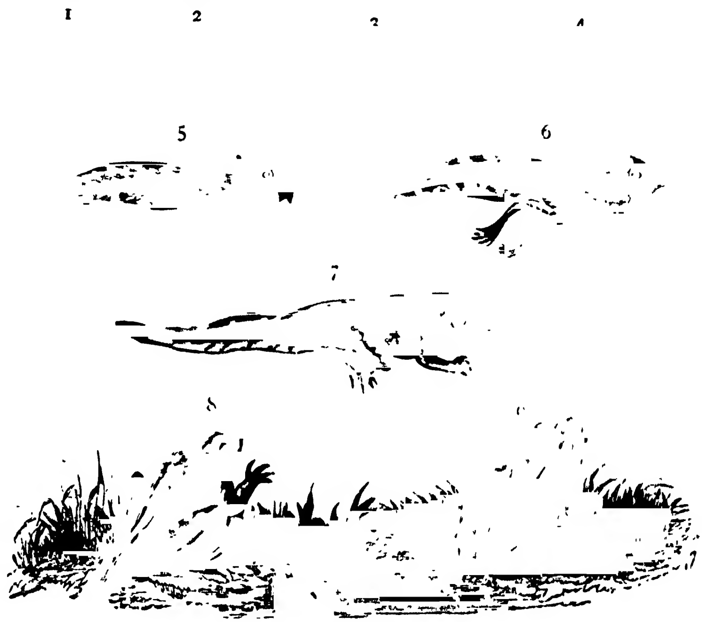

Fig. 2. –Metamorphoses of Frog.

(1) Egg of Frog; (2) Egg fecundated, and surrounded by its Vesicle; (3) First State of Tadpole; (4) Appearance of Breathing Gills; (5) Stage with Internal Gills; (6) Formation of Hind Feet; (7) Formation of Fore Feet, and Decay of Gills; (8) Development of Lungs and reduction of Tail; (9) Perfect Frog.

so far as research has proceeded, these changes appear common to the entire animal world. The beginning of development is ushered in by the egg-yolk undergoing a process of *segmentation* (Fig. 3), or division. This division proceeds most regularly, and only ends when the yolk has become divided into an immense mass of cells, so closely packed together that they somewhat resemble a mulberry; and hence the concluding stage of egg-segmentation is named the *mulberry stage*, or *morula* (Fig. 3, *h*). It is up to this stage that animal development at large appears certainly to coincide and agree.

The next changes consist in the formation of two membranes, by the development of which the young animal, or embryo, is to be formed. A groove, called the "primitive groove," appears in that part of the embryo which is to form the back region; and as this groove becomes a tube, and is shut off from the other regions of the body, we see in its

formation, the promise and outline of the nervous system of the future frog. Meanwhile the lower parts of the body are also being formed. The walls of the body grow downwards, and the organs contained within their compass are developed; and in due course the young frog makes its appearance—

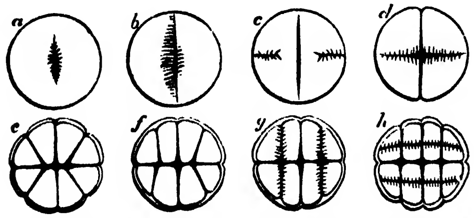

Fig. 3.—Segmentation of Frog's Egg: successive stages from the beginning of the process (*a*) to the Mulberry stage (*h*).

not in its adult form, as the four-legged, tailless animal we know it to be, but as the tailed, fish-like, gill-breathing form we name the "tadpole" (Fig. 2). Frog-development is not therefore completed when the tadpole stage is assumed. The natural expectation would be that when an animal is capable of moving about and feeding, and when, so to speak, it has finally left the egg and completed its preliminary stages of development, it should assume the form of the adult. And although this natural expectation is quite in consistence with what occurs in nature, as a rule, there are various exceptions to the rule that an animal assumes the adult form when it leaves the egg as an embryo. Of these exceptions insects form a notable example. Every one knows that usually the egg of an insect gives origin to a free-moving larva, or caterpillar, instead of to a winged insect. And the frogs, and toads, and newts—which are all near relations—are likewise illustrations of exceptional developments, in that they appear on the stage of time first as "larvæ," or tadpoles, and only assume their adult form after a series of changes, which properly belong to development, and which in other animals are usually passed within the egg. These changes, whether occurring in insect or frog, constitute what is known as the "metamorphosis" (Fig. 2, No. 4) of these animals.

The anatomy and further history of the fish-like tadpole are decidedly instructive (Fig. 4). On each side of the tadpole's neck appear two tufts, which we can have no difficulty in recognising as "gills," or breathing organs. Its tail is fringed by a soft fin which, however, unlike the fins of fishes, has no hard parts, or "fin-rays," to support it. It possesses horny jaws (Fig. 4 B, *j*), by which it crops the water-weeds—for although the adult frog is an insect eater, the youthful frog is a strict vegetarian; and coiled up within its body, we may perceive the spiral and lengthy intestine proper to the plant-eating form. But tadpole-life, as the youth of the animal, knows its own changes, as does the earlier infancy of the frog. Soon the outside gills (Fig. 4 A, B, *g*) disappear, and are replaced by internal gills (Fig. 2, No. 5), developed on the gill-arches in the neck; so that in such a stage of development the tadpole more than ever resembles the fish with its inside gills, placed, as everybody knows, beneath the gill-cover in the neck. Next appear the beginnings of adult characters in the sprouting of the limbs, which bud forth from the sides of the body; the hind limbs (Fig. 2, No. 6) first appearing, and the fore limbs being visible later on (Fig. 2, No. 7), because they are longer concealed by the gill-cover. When the legs are developed, the tail begins to "grow small by degrees and beautifully less;" and, as the tail decreases, the gills (Fig. 2, No. 8), as organs of breathing, likewise begin to disappear and to be replaced by the lungs—which

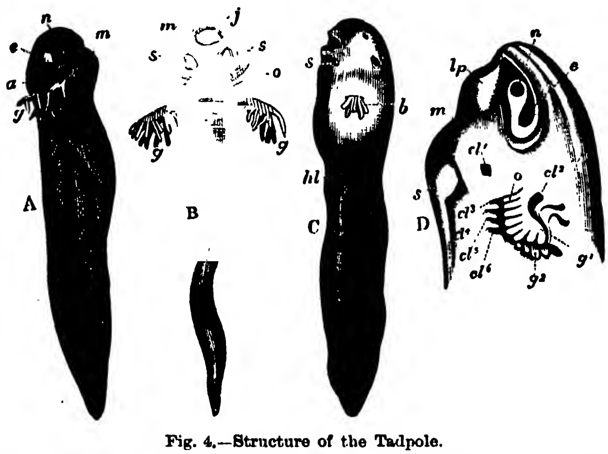

Fig. 4.—Structure of the Tadpole.

(A) Side View, showing Gills, *g*; Mouth, *m*; Nasal Sac, *n*; Eye, *e*; Ear, *a*; (B) from below, *ss*, Suckers; *o*, Operculum; *j*, Horny Jaws; (C) More Advanced Tadpole, showing growth of Operculum, so as to enclose Gills, save at opening *b* on left side; *hl*, rudiment of hind limbs; *s*, Sucker; (D) Head of young Tadpole (magnified); g^1 g^2, external Gills; *lp*, Upper Lip; cl^1 to cl^6, Visceral Clefts.

have been meanwhile growing—as the breathing organs proper to the adult. When tail and gills have become absorbed, the frog leaves the water, seeks the land, and becomes a true terrestrial breather and inhabitant (Fig. 2, No. 9); the small adult body growing rapidly, and in its second summer or so, attaining to full growth, as represented in frog-existence.

We are now prepared to answer fully the question, "What is a frog?" Having discovered that the animal begins life as a fish-like creature,

provided with gills and a tail, and that afterwards it breathes by lungs, we are at once confirmed in the opinion that it is certainly not a "reptile." For "Reptiles"—of which there are four living orders (lizards, snakes, tortoises, &c., and crocodiles)—never breathe by gills at any period of life, but possess lungs as their sole breathing organs. And again, all reptiles have scales or like body-coverings; but the frogs, and those animals which agree with them in development (toads, newts, &c.), want, as a rule, all traces of hard external parts. Thus we find that in reality the frog is much more nearly related to the fishes than to reptiles; and when we discover that some fishes, such as the *Lepidosirens* of Africa and America, may actually breathe by lungs as well as by gills, the likeness between frogs and fishes is considerably heightened. Frogs, toads, newts, and all animals allied to them, are named *Amphibians*, in allusion to their duplex breathing organs. In some of the amphibian race, such as the *Proteus* of underground caves in Central Europe, the Sirens (Fig. 5), &c., we find that the gills, which invariably appear in the early life of every amphibian, remain throughout life, and as the proteus or siren (like every other amphibian) develops lungs in its adult state, it follows that there are two chief divisions of amphibian animals. Firstly, there are those in which the gills of early life disappear when the lungs are developed: such is the case with the frogs, toads, and newts. Secondly, there are those amphibians in which the gills and lungs co-exist throughout life: such are the proteus, siren, axolotl (Vol. I., p. 82), and many other forms. If, lastly, we endeavour to discover other characters of the amphibian class (in addition to that presented by its members having gills in early life and lungs in adult existence) we shall find such characters to be presently illustrated in the person of our frog. Marks of difference from the reptile-race are to be seen in the three-chambered heart; in the skull being joined to the spine by *two* processes, or "condyles," and not, as in reptiles, by one only; and in the occurrence of a series of changes, called the "metamorphoses," which are exhibited in the development of amphibians, and which are not represented either in fishes on the one hand, or in reptiles on the other.

Fig. 5.—Siren lacertina, showing External Gills.

We thus discover our frog to be an amphibian animal, and as such to be included in the "Vertebrate" group in which fishes, reptiles, birds, and quadrupeds (including man) are likewise contained.

One feature in the history of the frog may be first alluded to as that with which all vertebrates agree, namely, that the general plan of the body consists of two parallel tubes—one existing in the back region of the animal (Fig. 6) where we saw the "primitive groove" to be formed, and containing the nervous system (n^2), brain, and spinal cord. This first tube (p^1) is formed by the skull and spine. The second tube (p^2) is formed by the walls of the body, and contains the other organs of the frame. These are arranged as follows:—The heart below (*h*), the digestive system in the middle (*a*), and a second nervous system, called the *sympathetic* (n^1), in front of the spine and above the digestive tract. Thus, even in a cursory examination of the frog, we learn the essential plan on which every vertebrate body, from that of the fish to the human frame, is constructed. The double tube arrangement seen in our amphibian is characteristic of every vertebrate form, but of no other type of animal structure. And every vertebrate animal (but no other) therefore carries its nervous axis along its back, its "sympathetic" nervous system beneath its spine, its digestive system in the middle of its body, and its heart lowest of all, or on the floor of its body.

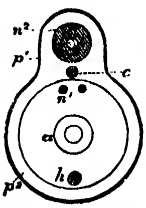

Fig. 6. — Transverse Section (Diagrammatic) of a Vertebrate Body.

Commencing our brief history of the frog with its skin-layer, we find that membrane (Fig. 7), like our own skin, to consist of two layers—one an upper or outer, called the *epidermis* (*b*) the other a sensitive under layer, the *dermis*, or true skin (*c*). In the frog the skin contains black pigment-cells (*a*) of a peculiar and irregular shape. Under stimulation, such as light, these cells undergo changes in shape and form, and the alterations in hue or colour to which the skin of the frog is subject are due to the movements of these cells. It is noteworthy that very large veins are distributed in the frog's skin, and the skin-glands (*d*), or those structures analogous to our "sweat-glands," are also highly developed. So that we can understand readily enough how the frog contrives to support life for a lengthened period when its lungs are excised, seeing that the skin in that case, as in the ordinary run of frog-existence, largely supplements or entirely performs the work of the lungs in getting rid of the waste matters brought to its glands by the blood-circulation. This work of getting rid of waste matters we name "excretion."

The frog's skeleton (Fig. 8) is worth studying from its general type being admirably adapted to convey to us an idea of the bony framework of vetebrate animals at large. The mainstay and support, or centre of the skeleton, is, of course, the *spine, back-bone*, or *vertebral column*, as it is named (Fig. 8, *v*). This spine is continued above into the skull; and, as we have seen, the brain contained in the latter organ becomes continuous with the spinal marrow protected within the back-bone. So that when we declare that every vertebrate animal, like the frog, has its nervous system partitioned off from the rest of its body, we declare a real character, and one of extreme importance in the history of the highest type of animal structure. The frog's spine is undoubtedly short; it consists, like man's spine, of separate bones or *vertebræ*, and these in the frog number nine. The tail-extremity of the spine is formed by a single piece named the *coccyx*, or *urostyle* (*c*), which in itself probably represents several united vertebræ. Above, each vertebra gives off a projection named the *spinous process*, and at each side bears two long pieces, called the *transverse processes* (*w*), which are apt to be mistaken for ribs. There are no ribs in the frog; and unquestionably the absence of ribs is an advantage to the animal in its leaping movements. But the want of these bones means also the absence of a *chest*, or *thorax*, and, as we can readily conceive, by a reference to our own movements of breathing, the frog must respire differently from ourselves—as, indeed, we shall presently note. The frog's skull is a complex structure, which need not be described in the present instance, further than to remark that it consists of so much *bone* and so much *cartilage*, or "gristle;" whilst, as already noted, it is joined to the skull by two processes or "condyles," which fit into hollows in the first vertebra or *atlas*.

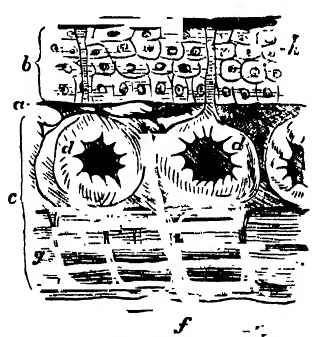

Fig. 7.—Vertical Section of Skin of Frog (magnified).
(*h*) Duct of Skin-gland; (*f*) Nerve-filament.

The frog has a well-developed *breast-bone* or *sternum*, and in its shoulder are several bony pieces not represented at all, or but feebly developed in ourselves; although the *collar-bone* or *clavicle*, and the *scapula* or *shoulder-blade* (*sc*), constituting the two elements in our own shoulders, are represented in the frog. The frog's arm, or fore-leg, is strictly comparable with our own in its structure. There

is a *humerus* (*h*), or bone of the upper arm, as in ourselves; two bones (*radius* and *ulna*, *r*), in the apparently single fore-arm of the frog, as in man; six *wrist* or *carpal* (*wr*) bones, instead of eight as in man; and but four fingers (*mc*), instead of five as in the human subject, the frog's thumb being rudimentary. Similarly, the hind limb and the haunch in the frog are modelled on the type common to all vertebrates. The frog's haunch-bone on each side consists of three pieces—*ilium* (*il*), *ischium*, and *pubis* (*p*)—as in man himself; and these three bones unite to form the deep cup (*acetabulum*) or socket in which the head of the thigh-bone works to form the hip-joint. The thigh-bone or *femur* (*f*); the *tibia* or shin, and the *fibula* (forming the "leg," *t*) united together; the ankle or *tarsus* formed in the frog of two chief bones only (*a a*), the *metatarsus* (*mt*) or "instep," formed, as in man, of five bones, and the five toes, represent segments of the lower limb corresponding in type, although differing in number, to the lower limb of man and to the hinder limbs of all other vertebrate animals.

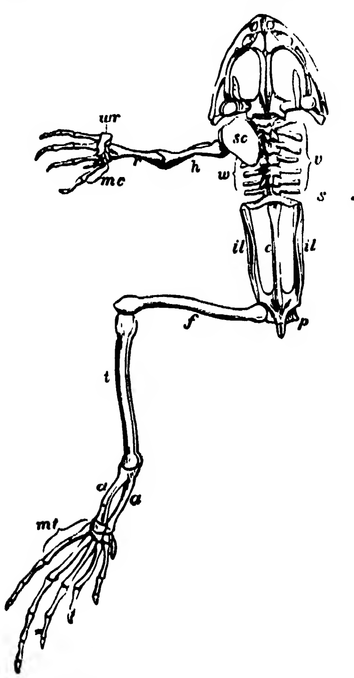

Fig. 8.—Skeleton of Frog.

There is little need in the present case to say anything about the *muscles* of the frog. "Muscle," as every one must know, forms the flesh of the body. When we eat beef and mutton we devour the muscle of the ox and sheep respectively; and although the flesh of the frog is not a dainty in repute on this side of the Channel, yet the muscular tissue of the amphibian is not to be despised as an culinary dainty. As in ourselves, the muscles of the frog enable the animal to execute the various movements of the body, and act under the direction of the nervous system as the ruling centre of the organism.

Digestion in the frog is performed by a very perfect set of apparatus. The teeth are small and insignificant, and are borne on the upper jaw and palate only; the lower jaw being unarmed. Gullet, stomach, intestine, liver, and sweetbread, or pancreas, constitute the furnishings of the frog's alimentary system; and a spleen also exists—this latter organ dealing with the elaboration of the blood. The food being converted into blood through the agency of the digestive organs, we find a *heart* and *blood-vessels*, provided for the *circulation* of that fluid. In the frog the heart (Fig. 9) is three-chambered, and circulates red blood, in which, when the microscope is employed, we can discern large red blood-corpuscles, giving colour to the blood, as in ourselves. The frog's heart is a peculiar piece of mechanism, and consists of two smaller chambers—*right* (RA) and *left* (LA) *auricles*—and a large chamber, the *ventricle* (V). The right auricle receives impure blood, which, having gone the round of the body, requires purification in the lungs. The left auricle, on the other hand, receives the purified blood from the lungs. Each auricle opens into the ventricle. From the ventricle a passage, called the *aortic bulb*, leads outwards to the body, and this passage is divided lengthwise in two by a swing-door or movable partition, called the *septum* (*s*). Last of all, we may note that from this passage two chief sets of blood-vessels, like two roads or lobbies, lead outwards (*ls*, *rs*). To pass into the one of these roads we should require to go on the right side of the swing-door, whilst the other and left side allows exit by the second of the two channels.

This mechanism is beautifully adjusted to the wants of frog-circulation; for we find that the left auricle throws its pure blood into the ventricle, whilst the right auricle also empties the impure blood into this cavity. When this common receptacle or ventricle contracts in its turn, whither does the blood pass? The answer is clear if we remember the disposition of the swing-door and the passages in the lobby of the ventricle. The first result of the ventricle's contraction is to send the venous or impure blood out of its cavity by the *left* passage (*ls*) of the lobby, the swing-door falling over towards and closing the right passage (*rs*); and thus the impure blood passes by the only channels (3, 3) open to it to the lungs for purification. A mixture of pure and impure blood has meanwhile been taking place in the ventricle, and as the swing-door now closes the left passage, this mixed blood is allowed to pass out through blood-vessels (2, 2), which convey it to the body—the frog's body thus receiving and being nourished by a mixed blood,

and not by an absolutely pure blood, as in birds and quadrupeds. Finally, as the last result of the ventricle's contraction, the perfectly pure blood which has just come from the left auricle is, by an ingenious adjustment of the blood-vessels, sent to the head and brain of the frog, as the most important parts of the body.

Thus the circulation of the blood in the frog, performed continually during its lifetime, is found

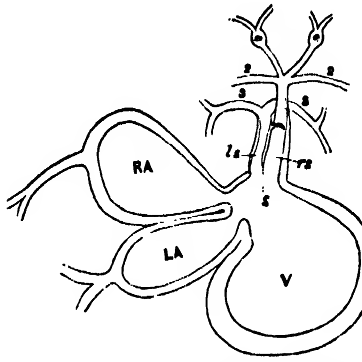

Fig. 9. -Diagrammatic (vertical) Section of Frog's Heart.

to involve a delicacy and exactness of mechanism which excites our wonder even when studied in the most superficial fashion. Space will not permit us to do more than notice in passing, that the work of "excretion," or that devoted to the getting rid of waste matters, is performed in the frog by means of two kidneys, by the skin-glands, and lastly, by the lungs—all of which organs, as in man, separate from the blood the waste products which, as the result of bodily work, are inseparable from life and living. The lungs are elastic sacs, into which air is "swallowed" by the frog rather than "breathed." As we have seen, no ribs exist in these animals; hence, when the inhalation of air occurs, the frog first fills its mouth through the nostrils. Next in order, the hinder nostrils are closed by the tongue being applied thereto, and the gullet is also closed by the same action. The only aperture remaining open being that of the windpipe, the air is forced into the lungs by the muscular action of the muscles of the sides of the mouth; whilst "expiration" is a work probably effected wholly, or in greater part, by the elasticity of the lungs.

That the frog possesses means for maintaining relations with its surroundings is perfectly evident. It captures prey, it sees, it hears, it emits voice, and it regulates its actions, muscular and otherwise, in conformity with the exigencies of its life. The acts of frog-existence, like those of all other animals, are regulated by the chief *nervous system*, consisting of the *brain*, *spinal cord*, and *nerves* proceeding therefrom. The *sympathetic system* of nerves already mentioned, possesses the function of regulating the movements of the heart and other actions of involuntary nature. The brain (Fig. 10) of the frog exhibits the chief divisions common to all brains. Looking down on the brain from above, we see in front (1) the *olfactory region* (*ol*), or that connected with the sense of smell; (2) the *cerebrum* (*c*), or chief part of the brain; (3) the *optic thalamus* (*t*); (4) the *optic lobes* (*op*), connected with the nerves of sight; (5) the *cerebellum* (*cb*), or lesser brain; and (6) the *medulla oblongata* (*m*), or upper part of the *spinal cord* (*sp*). If we suppose parts 2 (the cerebrum) and 5 (the cerebellum) to become immensely enlarged, and developed over the other parts of the brain, we should represent the chief difference between man's brain and that of the frog. From the frog's brain ten pairs of (*cranial*) nerves, chiefly connected with the organs of sense, are given off, and a like number of nerves originate from the spinal cord and are distributed throughout the body.

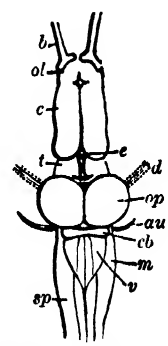

Fig. 10.—Brain of Frog.

(*b*) Olfactory Nerves; (*e*) Pineal Gland; (*d*) Origin of Optic Nerves; (*au*) Auditory Nerves; (*v*) Position of Fourth Ventricle.

The general deductions which may be drawn from this brief study of the frog have been indicated as our history has proceeded. We thus learn from the frog's anatomy not merely the general plan of all vertebrate animals, but a general review of such a history presents us with the salient points of man's own structure and physiology; for man's body undoubtedly exhibits a type of structure modelled on the broad lines on which that of the frog has been shown to be built up. And it may be added that if we could correctly appreciate and fully understand the true meaning and bearings of even the changes through which a frog passes in the course of its progress to maturity, we should find ourselves thereby enabled to add very largely to our knowledge of animal history at large; and even many obscure points in human development could be shown to be bound up in the answer to the common-place question—"What is a frog?"

WHY A TOP SPINS.

By William Alford Lloyd.

BOY-LIKE, I follow on foot a street conjurer, in London, hoping that he will soon stop and perform. At length he slackens his pace, looks about him, pauses, and divesting himself of his walking boots, coat, and hat, spreads on the ground the square yard of carpet, which is his stage, and near it temptingly arranges his opened box of paraphernalia, comprising brass balls, cups, knives, and so forth. His orchestra, consisting of pan-pipes and drum, played by his "mate," soon gathers a small crowd, the inner limits of which are, however, speedily determined by the conjurer, now radiant in a spangled suit of light-coloured "tights," for he takes out of his overcoat pocket a long cord, and, holding it by the middle, causes two great soft balls, one at each end, to whirl rapidly over his head, skirting and all but touching the edge of the quick-gathering mob of people, who, not caring to be struck by these fast-swinging balls, keep just out of their reach, and thus a clear area is secured for the performance. And the movement of these balls furnishes me with a good beginning for my paper. Why do these balls thus remain in the air, pulling as they do at their string, keeping it straight and a little tight, and themselves turning round the conjurer in the centre? The answer is that the power that compels them thus to traverse a definitely bounded circle is due to what is called the *centrifugal force*, the word "centrifugal" being composed of two Latin words signifying the *flying from a centre*. And the other force, indicated by the cord or string which hinders the balls from flying from the centre, is termed *centripetal force*, a term that means *seeking a centre*.

Thus, these two forces, combined with a third force (Fig. 1), which arises from their union, and which vainly tends to cause the balls to traverse a horizontal line, conjoined with a fourth and last force, or gravitation of the earth, which tends to pull down the balls vertically, all unite to maintain the balls in their revolving path, and in such a manner that this circuitous motion would be at once destroyed if any one of the four forces ceased to exist, or existed inadequately. And, in fact, cessation of the motion is ultimately brought about by the arrest of one or more of these forces. Presently, however, the street conjurer or acrobat takes out of his box a great spinning-top, and it is about a top that I have to write. Now, the etymology of the word "top" points to its derivation as being that which means that its upper part or *top* is heavier than its lower part, or, where the upper or *top* end is the principal one, and this, undoubtedly, is the strict etymological meaning of the word or term. But, for my purpose, which is that of elucidating, on philosophical principles, the reason why it turns round and maintains its rotation, I will extend the term into meaning *any* such arrangement, as that which so revolves, no matter whether its centre of gravity, or balancing point, be above or below the point of support on which rotation occurs, or whether these two points occur in the same plane.

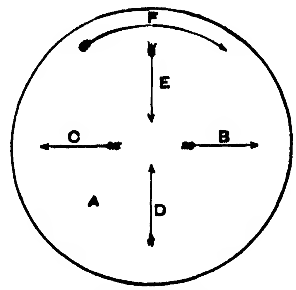

Fig. 1.—Showing how Two Forces are united to make a Third.

(A) Horizontal Section of Top; (BC) Centrifugal Force; (DE) Centripetal Force; (F) Circular Inertia, made up of B, C, D, E.

The top which the acrobat is about to perform with, is made large for effect, and is a pear-shaped mass of solid wood, conical, with a rounded upper end, and in the small or lower end is inserted a stem or peg of iron. The lower part of the wood is closely grooved or corrugated, transversely, to receive the string or cord, which is wrapped round it so that it may not slip. I watch the man coil it. First, he takes the end of his string, and wetting it in his mouth that it may be a little adhesive to the wood, he applies this cord's end flatly to the top furrows, across them. Then, with some care and considerable firmness, he commences to coil the string around the top, in the grooves, beginning at the smaller or lower end, and going gradually upwards, terminating at the top groove, and taking care that the spirally coiled-on string shall form a closely-touching and completely-covering mass. Then, holding with his right-hand third finger the free end of the string against the palm of that hand, he grasps the widest part of the top between his thumb and third (or longest) finger, thus at the same time holding the string secure, and then he further increases the firmness of the top in his hold by pressing down

and not by an absolutely pure blood, as in birds and quadrupeds. Finally, as the last result of the ventricle's contraction, the perfectly pure blood which has just come from the left auricle is, by an ingenious adjustment of the blood-vessels, sent to the head and brain of the frog, as the most important parts of the body.

Thus the circulation of the blood in the frog, performed continually during its lifetime, is found

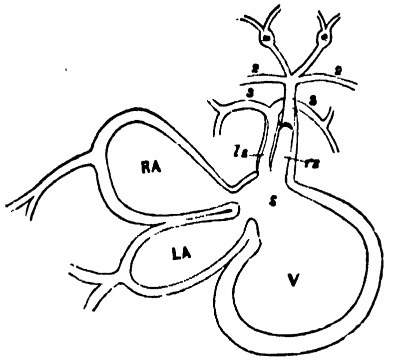

Fig. 9.—Diagrammatic (vertical) Section of Frog's Heart.

to involve a delicacy and exactness of mechanism which excites our wonder even when studied in the most superficial fashion. Space will not permit us to do more than notice in passing, that the work of "excretion," or that devoted to the getting rid of waste matters, is performed in the frog by means of two kidneys, by the skin-glands, and lastly, by the lungs—all of which organs, as in man, separate from the blood the waste products which, as the result of bodily work, are inseparable from life and living. The lungs are elastic sacs, into which air is "swallowed" by the frog rather than "breathed." As we have seen, no ribs exist in these animals; hence, when the inhalation of air occurs, the frog first fills its mouth through the nostrils. Next in order, the hinder nostrils are closed by the tongue being applied thereto, and the gullet is also closed by the same action. The only aperture remaining open being that of the windpipe, the air is forced into the lungs by the muscular action of the muscles of the sides of the mouth; whilst "expiration" is a work probably effected wholly, or in greater part, by the elasticity of the lungs.

That the frog possesses means for maintaining relations with its surroundings is perfectly evident. It captures prey, it sees, it hears, it emits voice, and it regulates its actions, muscular and otherwise, in conformity with the exigencies of its life. The acts of frog-existence, like those of all other animals, are regulated by the chief *nervous system*, consisting of the *brain*, *spinal cord*, and *nerves* proceeding therefrom. The *sympathetic system* of nerves already mentioned, possesses the function of regulating the movements of the heart and other actions of involuntary nature. The brain (Fig. 10) of the frog exhibits the chief divisions common to all brains. Looking down on the brain from above, we see in front (1) the *olfactory region* (*ol*), or that connected with the sense of smell; (2) the *cerebrum* (*c*), or chief part of the brain; (3) the *optic thalamus* (*t*); (4) the *optic lobes* (*op*), connected with the nerves of sight; (5) the *cerebellum* (*cb*), or lesser brain; and (6) the *medulla oblongata* (*m*), or upper part of the *spinal cord* (*sp*). If we suppose parts 2 (the cerebrum) and 5 (the cerebellum) to become immensely enlarged, and developed over the other parts of the brain, we should represent the chief difference between man's brain and that of the frog. From the frog's brain ten pairs of (*cranial*) nerves, chiefly connected with the organs of sense, are given off, and a like number of nerves originate from the spinal cord and are distributed throughout the body.

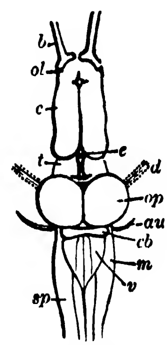

Fig. 10.—Brain of Frog.

(*l*) Olfactory Nerves; (*e*) Pineal Gland; (*d*) Origin of Optic Nerves; (*au*) Auditory Nerves; (*v*) ... of Fourth ...

The general deductions which may be drawn from this brief study of the frog have been indicated as our history has proceeded. We thus learn from the frog's anatomy not merely the general plan of all vertebrate animals, but a general review of such a history presents us with the salient points of man's own structure and physiology; for man's body undoubtedly exhibits a type of structure modelled on the broad lines on which that of the frog has been shown to be built up. And it may be added that if we could correctly appreciate and fully understand the true meaning and bearings of even the changes through which a frog passes in the course of its progress to maturity, we should find ourselves thereby enabled to add very largely to our knowledge of animal history at large; and even many obscure points in human development could be shown to be bound up in the answer to the common-place question—"What is a frog?"

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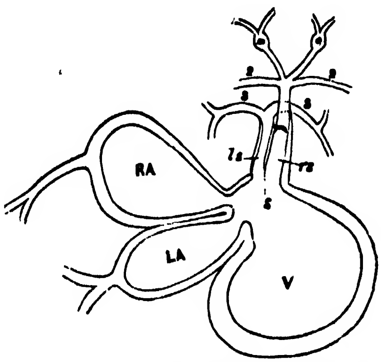

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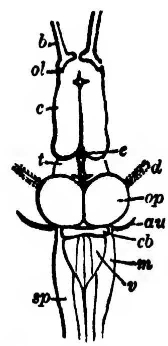

Fig. 10.—Brain of Frog.

(*b*) Olfactory Nerves; (*e*) Pineal Gland; (*d*) Origin of Optic Nerves; (*au*) Auditory Nerves; (*v*) Position of Fourth Ventricle.

The general deductions which may be drawn from this brief study of the frog have been indicated as our history has proceeded. We thus learn from the frog's anatomy not merely the general plan of all vertebrate animals, but a general review of such a history presents us with the salient points of man's own structure and physiology; for man's body undoubtedly exhibits a type of structure modelled on the broad lines on which that of the frog has been shown to be built up. And it may be added that if we could correctly appreciate and fully understand the true meaning and bearings of even the changes through which a frog passes in the course of its progress to maturity, we should find ourselves thereby enabled to add very largely to our knowledge of animal history at large; and even many obscure points in human development could be shown to be bound up in the answer to the common-place question—"What is a frog?"

WHY A TOP SPINS.

By William Alford Lloyd.

BOY-LIKE, I follow on foot a street conjurer, in London, hoping that he will soon stop and perform. At length he slackens his pace, looks about him, pauses, and divesting himself of his walking boots, coat, and hat, spreads on the ground the square yard of carpet, which is his stage, and near it temptingly arranges his opened box of paraphernalia, comprising brass balls, cups, knives, and so forth. His orchestra, consisting of pan-pipes and drum, played by his "mate," soon gathers a small crowd, the inner limits of which are, however, speedily determined by the conjurer, now radiant in a spangled suit of light-coloured "tights," for he takes out of his overcoat pocket a long cord, and, holding it by the middle, causes two great soft balls, one at each end, to whirl rapidly over his head, skirting and all but touching the edge of the quick-gathering mob of people, who, not caring to be struck by these fast-swinging balls, keep just out of their reach, and thus a clear area is secured for the performance. And the movement of these balls furnishes me with a good beginning for my paper. Why do these balls thus remain in the air, pulling as they do at their string, keeping it straight and a little tight, and themselves turning round the conjurer in the centre? The answer is that the power that compels them thus to traverse a definitely bounded circle is due to what is called the *centrifugal force*, the word "centrifugal" being composed of two Latin words signifying the *flying from a centre*. And the other force, indicated by the cord or string which hinders the balls from flying from the centre, is termed *centripetal force*, a term that means *seeking a centre*.

Thus, these two forces, combined with a third force (Fig. 1), which arises from their union, and which vainly tends to cause the balls to traverse a horizontal line, conjoined with a fourth and last force, or gravitation of the earth, which tends to pull down the balls vertically, all unite to maintain the balls in their revolving path, and in such a manner that this circuitous motion would be at once destroyed if any one of the four forces ceased to exist, or existed inadequately. And, in fact, cessation of the motion is ultimately brought about by the arrest of one or more of these forces. Presently, however, the street conjurer or acrobat takes out of his box a great spinning-top, and it is about a top that I have to write. Now, the etymology of the word "top" points to its derivation as being that which means that its upper part or *top* is heavier than its lower part, or, where the upper or *top* end is the principal one, and this, undoubtedly, is the strict etymological meaning of the word or term. But, for my purpose, which is that of elucidating, on philosophical principles, the reason why it turns round and maintains its rotation, I will extend the term into meaning *any* such arrangement, as that which so revolves, no matter whether its centre of gravity, or balancing point, be above or below the point of support on which rotation occurs, or whether these two points occur in the same plane.

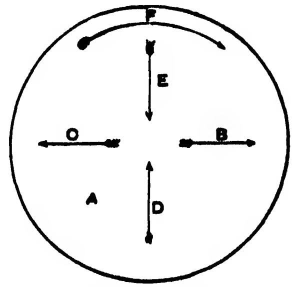

Fig. 1.—Showing how Two Forces are united to make a Third.

(A) Horizontal Section of Top; (BO) Centrifugal Force; (DE) Centripetal Force; (F) Circular Inertia, made up of B, O, D, E.

The top which the acrobat is about to perform with, is made large for effect, and is a pear-shaped mass of solid wood, conical, with a rounded upper end, and in the small or lower end is inserted a stem or peg of iron. The lower part of the wood is closely grooved or corrugated, transversely, to receive the string or cord, which is wrapped round it so that it may not slip. I watch the man coil it. First, he takes the end of his string, and wetting it in his mouth that it may be a little adhesive to the wood, he applies this cord's end flatly to the top furrows, across them. Then, with some care and considerable firmness, he commences to coil the string around the top, in the grooves, beginning at the smaller or lower end, and going gradually upwards, terminating at the top groove, and taking care that the spirally coiled-on string shall form a closely-touching and completely-covering mass. Then, holding with his right-hand third finger the free end of the string against the palm of that hand, he grasps the widest part of the top between his thumb and third (or longest) finger, thus at the same time holding the string secure, and then he further increases the firmness of the top in his hold by pressing down

upon it his index finger, the peg being all the time downwards-pointing. Then, first drawing up his hand somewhat towards his ear, so as to accumulate power, as it were, he gives his hand, and the top in it, a sudden jerk forwards, at the same time releasing the hold which his fingers had upon it, while, with a simultaneous motion, he, with a powerful back stroke of his hand and arm, pulls away or uncoils the string from off the top, which is caught on his palm, or otherwise disposed of. If the string were fastened to the top firmly, as by glue, for instance, and was thus in a state of dry adhesion, this jerk of the man's hand would merely pull the top forward. Instead of which, however, the pull is at the periphery or edge of the top's circumference, and acts as a lever, of which one point is the centre of the top, inside it, and the other point is at its outer surface. This sudden pull or jerk, therefore, instead of dragging the top bodily towards the puller, merely acts on the leverage provided as described, so as to turn the top round. And, as the pull is given with considerable force, and as, moreover, the length of the string causes the pull to be a tolerably continuous one—which, indeed, increases in speed and power as the inertia of the puller's arm gains force thereby—the rotation which the top thus gains is one of considerable force and speed. And then commences the exercise of the same kind of centrifugal force in the top as that which we saw being exercised when the two balls were whirled round at the two ends of the cord.

Only in the top, the wood or other material of which it is made has to sustain this outward pull or strain, or flying from a centre, or tendency to do so. While it is thus spinning or whirling round, the top stands upright on its polished blunt point, and the faster it turns, on a smooth and hard surface (the smoother the surface the less is the top's motion), impeded by friction or rubbing, the more upright does it stand, and the less tendency does it have to fall or to lose any portion of its perpendicularity. Or, if anything, as a jerk caused by roughness, or a sudden inclination from horizontality, occasioned by a sudden change of position of whatever it whirls upon, temporarily affects the top, it survives this momentary interruption, and spins as steadily and as uprightly as before, if its speed be high. But the reason why it thus pulls itself up straight, so to speak, is because the centrifugal force, or flying outwards, has a strength of horizontal pull, as it were, commensurate with its speed, the pull being greatest when the speed is highest. Yet, centrifugal force alone would not cause a recovery of the perpendicularity, which is finally attained because the top's peg is not absolutely pointed. It is a blunt point, and when the top whirls sideways it rolls on the edge of this point, till the axis of it is at right angles with the plane on which it spins. Hence, such a top can be made to spin balanced on the edge of a sword, or on a wire held horizontally, or nearly so. And, when—by gradual expenditure of the stored-up force—the speed is lessened, the top tends to lean sideways, or to deviate from the perpendicular, such deviation or leaning being caused by the superincumbent weight of the top obeying the earth's gravitation, or the power which our globe has of drawing all things smaller than itself towards itself; the term "weight" being thus an expression of the measure of the resistance made to this attractive force of the earth. Therefore, the top is maintained spinning in an upright position by a combination of two forces—(1) the force of the earth's gravitation, or *pull downwards;* (2) the force of centrifugality, which *pulls horizontally* the top in all directions at once. And the combination of these two forces maintains the top in a vertical position, which thus becomes a kind of compromise between the two powers. Thus the top, when it spins on a smooth surface, whirls immovably as regards deviation from verticality, and is so silent and motionless, horizontally, in its rapid whirlings, that it is, to use a schoolboy term, "asleep." We may get a very plain illustration of this fact—plainer because the motion is slower—by seeing a boy trundle a hoop. When the motion of the hoop relaxes in speed it begins to "wobble," or to have a tendency to fall alternately sideways, because the slowness with which it turns no longer completely resists the gravity, or downward pull of the earth. But, when the boy gives it a forward blow with his stick, the force of the blow corresponding with the speed with which he desires it to go, and with the nature (rough or smooth) of the ground over which it has to travel, he restores it, by the increased speed thus given it, to its normal uprightness. That is to say, the additional centrifugal force thus acquired, or the added power of pulling or flying from the absent or ideally present centre of the hoop, pulls up the hoop against the power of gravity, which sought to pull it down, and so renews its verticality. It is exactly the same with a whipping-top. When it begins to lose steadiness by reason of loss of speed, just as in the case of the hoop, it regains vertical quiescence by an increase of velocity given it by a stroke of the lash of the whip. Only, in the assumed

instance of the hoop, the fact was rather more obvious, because its motion was slower than that of a top. The form of carriage called a "bicycle" is another form in which the same law can be exemplified in a similarly plain manner. As we all know, a bicycle consists of two wheels, a large one and a small one, placed in one longitudinal line, and a man, seated on a saddle attached to the former, drives on the machine by converting the vertical up and down action of his feet into a curvilinear motion, which is transmitted by treadles (on which his feet are placed) affixed to the axis of the larger wheel, one on each side, and so arranged as to have no "dead points," or no position where a pressure on the treadles—one or both—cannot urge on the machine along the ground. The bicycle is thus balanced on a very small relative point, or, rather, two small points (though I have seen even a *unicycle* ridden upon, having but *one* wheel, as its name implies), and these two points are insufficient in area for the apparatus to stand upright upon alone, still more so when a man is riding on it, and to be absolutely motionless, because, practically, his tendency is to be drawn over by the force of gravity of the earth to one side or other, and to fall down laterally in the direction of the earth's centre, in consequence of this power, and with a constantly increased velocity. Consequently the man on the bicycle never keeps motionless, but rides forward constantly, because at every portion of the rotation of the wheels he is exercising a slowly-acting centrifugal power which every moment *pulls up*, as it were, the machine, and so creates a force greater, for the time, than the force of the earth which has a disposition to *pull down* the man and his bicycle. If the rider goes fast, then the centrifugal force which he exercises is, as in the case of the slowly-spinning top, a feeble force; but if he progresses quickly, the force exerted against the gravity of the earth is correspondingly great, and his chances of falling down are commensurately decreased.

These illustrations, where the speed of motion is so much diminished that the eye can easily follow every part of a gyration, are of considerable value to elucidate the motion of other objects, as a top, where such continuous vision is not possible, and when one cannot so easily watch the conversion of the *straight line*, which the pull of the earth causes, into the *curved line* which the centrifugal force compels the object to take (Fig. 2). But, indeed, if we pursue the idea as far as possible, a curved line may be considered to be, and in fact is, nothing more than a vast series of most infinitely small straight lines. Therefore, all movements whatever, conceivable or possible, in everything or everywhere, cannot be any other than a very rapidly-repeated and very minute succession of straight lines. The inertia, or tendency to move onwards in a straight line (the word "inertia" being the contrary of the word "motionless" in its meaning), of a moving body always strives to follow such constrained curved prolongations of a small straight line traversed at any given moment. But whenever a body is thus compelled to move in such a

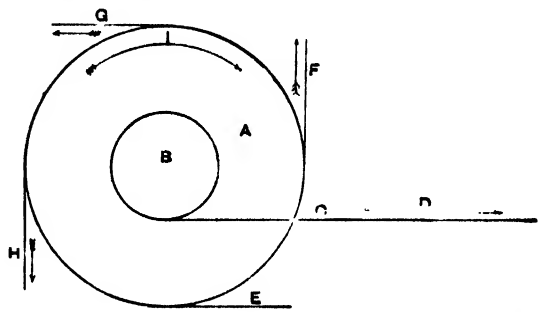

Fig. 2.—Showing how the Straight Line, C, is converted into a Curved Line, I, and reconverted into other Straight Lines, E, F, G, H.

(A) Horizontal Section of Top; (B) part of A, with String wound on; (C) pulled in direction of D; (E, F, G, H) straight lines into which the first straight line is again converted.

circle, composed as it is of an infinitely multiplied series of small straight lines, such compulsion must be, and can only be, due to some obstacle or some force, which thus compels it to traverse a path which we, from its final shape, term curvilinear, or some combination of a curve. Now, the force or obstacle which thus, in a top, continually interrupts the tendency of every particle of it to fly from the centre of it, is termed the *centripetal* force, and it is exactly opposite to the other or *centrifugal* force, which causes a tendency in exactly the opposite direction. And so, finally, the top is maintained erect and spinning, without time or opportunity for falling, just the same as when two boys pull with equal force at either end of a rope, which does not break, and which ends with the no-progress of either. Thus the circular movement of the top, or a movement which we find convenient to term circular, arises really from its tendency to continue a *tangential* movement, or a straight motion in a direction which is at a right angle to its circumference, and from this inclination being influenced by a constrained approach, or a forcible continuance of one uniform distance from a central point. Thus, too, *centrifugal* force is the force which tends to cause all parts of the outer edge of a top to fly out into

straight lines, and *centripetal* force is the other force which is the obstacle to this. And a union of these two forces thus breaks up the one straight line, which there is a tendency to traverse, into an enormously vast number of very small straight lines, which traverse a circle. This explanation, coupled with the other one respecting the gravitating power of the earth, explains not only the spinning motion of a top, but the motion in every and all directions of all bodies whatever, including not only those upon the earth and beneath its surface, but also all the celestial bodies above and surrounding the earth. If one fasten a stone to a string, and whirl it round, the pull of the centrifugal force can be felt in the hand which holds it, and which, in effect, constitutes the centripetal force. And if the string breaks, we see an instance of the curvilinear motion regaining its straight course, from which, indeed, it originated. And when such a string is intentionally interrupted in continuity by other means than breakage or severance, as in the ancient military weapon of offence called the "sling and stone," such an appliance is merely a means of accumulating in the stone a greater force, or "dynamical power," in a circular direction, by means of the acceleration permitted in a small space which such rotation gives; and then, when the speed and accompanying force are both, as they should be, at their maximum, one-half of the sling is disengaged, and the stone assumes, or rather, resumes, its onward straight flight, or, more correctly stated, its flight in a circuit of a much less radius than before; because, in the one case, that radius was defined by the length of the sling, and in the other case, it was marked out by the attractive power of the earth. The difficulty in using this weapon must have consisted in not knowing exactly at what point to disengage the restraint of the sling, so as to permit of the stone taking an accurately determinate new direction. A horse-rider in a circus, and the steed he stands on, have to lean much inwards when going fast, such leaning being to counteract the tendency of the centrifugal force to cause an upset by flying out. But, a still more homely illustration of the tendency of bodies moving rapidly in a curved line, to assume the direction of straight lines, can be witnessed by watching the particles of mud fly off at a tangent from the rapidly-revolving wheels of carriages in a muddy road. If a carriage goes slowly, no mud will be thus thrown off; but, when the edges of the wheels rotate swiftly, the particles can be seen flying away in straight lines, commencing at the part of the wheel which last came into contact with the mud, and thus flying upwards in perfectly straight lines, as if anxious to resume their primary form of flight, and desirous not again to resume a circular motion. Hence, "splash-boards," as they are called, they being guards attached a few inches from the periphery of the wheels, are used in carriages, to protect their occupants from such mud. Another familiar instance of matter being desirous to regain straight lines of flight, after having been compelled to take curvilinear ones, is afforded by the trundling of a mop. If we wish to get rid of the superfluous water which the mop-head has taken up in being used, we hold the long handle of it horizontally, and give it a rapidly-revolving motion around its own axis. Each fibre or string of which the mop-head is collectively composed, then becomes straight, because pulled at by the force termed *centrifugal*. But they cannot get away, because they are retained to the mop, or are pulled at by the force termed *centripetal*. The water, however, is held in *its* place in turn by a very far smaller amount of centrifugal force, and the centrifugal power, therefore, instantly severs its connection from the mop, and the fluid flies out in all directions in the familiar straight lines which we all have seen. And they *are* straight, and they do *not* follow the curves which the mop takes, simply because the order of nature is that they shall, as quickly as possible, regain as much straightness as the wonderful law of gravity permits. In an almost exactly similar manner are made clothes' driers, where freshly-washed linen is placed in a kind of rapidly and horizontally-revolving cage, through the interstices of which, as much wet is extracted as can be got rid of by such means, and which does not injure the fabrics so much as the more common practice of wringing does. So, too, sugar is extracted from the sugar-cane by a similar process, depending on this universal law. The speed of a top which went for 40 minutes has been found to be 4,500 revolutions a minute, or in all 180,000. Each point of the top's greatest diameter, therefore, of 4 to 5 inches, travelled 40 miles in that period, or a *mile a minute*. The friction of air much diminishes the speed. Thus, a top which in air spun for 35 minutes went for 136 minutes in a vacuum, and when in air it again went for 42 minutes: this speed was reduced to 17 minutes on the top being made rough by varnishing.

It is scarcely necessary to enter minutely into the specific construction of each kind of top which boys use. I have named the most common, which is the

"peg-top," and also the "whipping-top," which is the only one I know of which permits its motion to be accelerated after it has once begun to spin. There is the "humming-top," which is hollow, and which makes a sound, partly by the centrifugal force with which the air is ejected from it, and partly by the motion of the edge of the hole giving access to its interior, against the surrounding air. In this top the cord which converts the straight into a curved motion is coiled up within the portion of the handle which preserves the vertical position of the top until the commencement of spinning. The "gambling" top has no string, and is set in motion by the twist of the fingers merely. Then there is the "aërial" top, consisting of feathers fixed in such a manner, obliquely and horizontally, into a small block of wood or cork, that when spun, these feathers act like vanes, and so strike against the surrounding air that they overcome the force of gravity, and rise up to a considerable distance, only commencing to fall at the moment when the attraction of the earth on the one hand, and the cessation of the impact of the feathers against the atmosphere, on the other hand, balance each other. Nearly similar to this is a round, solid, and heavy wooden ball, of about three inches in diameter, which my street conjurer threw up to an immense height, and then caught in its descent in a sort of strong leathern egg-cup strapped across his forehead, the ball entering the cup with a mighty whack. But, as he explained to me, he gave the ball a strong twist as he threw it up. This gyration it maintained both in its ascending and descending, and, reverting to the old primary cause, the centrifugal or spinning force it thus acquired and retained, caused it to maintain a much straighter line of flight, and enabled it to be caught in the cup much more certainly than if it made no such revolutions. Indeed, all the things which this conjurer threw up, as knives, plates, balls, whirled round at every inch of their progress for the same reason; that is to say, they *spun* because the spinning set up a double force which tended to preserve their equilibrium by pulling them ever in two ways at once, and left the street conjurer not much more than the gravity of the earth to contend with, and, as the articles were but light in weight, this contention was not a great one. It was only when a spinning plate (on the top of a stick on his chin) began, in his own words, "to wobble," because of the gradually diminished rotation, that he gracefully declined the unequal contest with nature, and caught in his hand the falling plate, with a bow to the spectators. The "Radiometer"*—which turns in a vacuum in a wondrous manner by the mechanical force or impact of heat and light, which are inseparable—is not strictly and etymologically a top, because its centre of gravity is not over or on "top" of the point on which it spins. One remarkable top, of a complicated form, is termed the "gyroscope," and it has a demonstrating value because it can be *handled* as it spins with no retardation of speed. It consists of a wheel rotating within a ring placed on a stand, and if, during rapid motion, this ring and wheel be held in one's hand, there can be felt a curious innate feeling of striving to escape, as it were, reminding one of the consciousness of an imprisoned animal trying to be free. This is owing to the resistance of the moving mass to any attempt to change its axis of rotation. A weight can be hung on the edge of the ring, and the spinning will resist the force of the weight. Even the ring can be suspended in the air by a string, and the revolving wheel will retain its horizontal plane though wholly hung up by one side. Here, again, the law of the composition of forces is at work in the shape of the admixture of centrifugality and centripetality, and the property of inertia is shown in such a way as to demonstrate that matter at rest cannot move of itself, and matter in motion cannot stop of its own accord. And hence the gyroscope *apparently* resists the earth's gravity, while also it, in a very faithful way, exhibits that curious phenomenon of our globe known as the "precession of the equinoxes," both existing from the same cause. In 1851 Dr. Bateman showed such a centrifugal machine to illustrate planetary motion. Then come other arrangements, all on the top principle as far as the gyrating result is concerned, though not necessarily so in respect of the situation of the centre of gravity, as, for example, the fly-wheel of many forms of machinery, whether they be prime motors or not. Others are those which, unlike regular fly-wheels, make a not quite complete revolution of a circle, such as the balance-wheels of watches and the pendulums of clocks, and the ball-levers of coining and other presses of sudden but forcible impact. Watt's ingenious ball steam-engine governor is also an instance of an application of a top to a useful purpose, in which the centrifugal and centripetal force in it (and in all these cases) is employed for definite ends, calculated beforehand. What is termed the "rifling" of

* "Science for All," Vol. I., p. 111.

projectiles is likewise a direct application of the same law exactly. The earliest arrows ever made, discharged by an archer from a bow (perhaps preceded however by the thrower of javelins), were "barbed" at the opposite end to that of the pointed one, with feathers or some such light material, to cause the weapon to "catch the air," or retard the hinder end by friction in flying, so as to make the sharp end to always keep in front. After a while, however, someone thought of giving the feathers a measure of obliquity, so that during its progress the weapon should *revolve*. The use of such revolution is of course to give more accuracy of flight and aim by causing the centrifugal and centripetal principles to be brought to bear on the arrow. Thus, if any impulse were given to it which would tend to cause it to deviate from a certain course, its revolution instantly assists to pull it straight, and hinders an otherwise erratic path, while the opposite pull (centripetality) prevents its separation into several pieces. Rifled guns, pistols, and cannon, of all kinds, owe their superior accuracy to the same great law, the recent application of which to firearms seems quite wonderful, as no weapons at Waterloo were rifled: all shots of all sizes on that memorable day flew straight, untwistingly, and with but feeble accuracy of aim, which indicates the great waste of material which modern science tends to prevent in every way. A shot from a rifled weapon has, so to speak, no time to fall from its path or deviate from its course, for as soon as its inclination to turn in a wrong direction is indicated, the action of another inclination instantly neutralises the first one, and a nearly straight line is the sum of both.

Another group of top-like machines is that to which turbines belong. These, and "Barker's Mill," or the re-action mill, are prime motors, in which a forcible current of a fluid, hot or cold, or a gas of any kind, passes into a usually vertical axis, at one end of which are, at right angles to it, several arms having orifices again at right angles to those arms, through which the fluid in forcible motion escapes, and the arms and the hollow spindle or axis supporting them are driven in the opposite direction to that in which the water, gas, or air flows, and with a force and speed corresponding to the pressure of the flowing agent (Fig. 3). Here, too, the same old centrifugal and centripetal forces are employed, but it is remarkable that many persons wrongly explain this motion thus obtained by referring it to the issuing current, fluid or aërial, or hot or cold, striking against the surrounding air, or other medium, and so pushing the arms backwards; just the same, for example, as a man accidentally running against a wall would be pushed backward by the shock. The real cause, however, is *the force of the internal unbalanced pressure* acting inside the object moved in the direction of its path, exactly the same as the recoil of a cannon, or the "kick" backwards of a gun, is caused not by the explosion at the cannon's mouth, but by the *internal* explosion, which sends the light object (the shot) a long way onwards, and

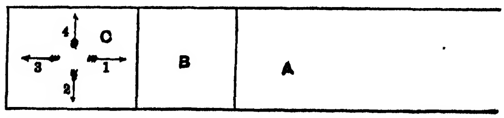

Fig. 3.—Illustrating Turbine Motion or Recoil of any kind, as in the Tops spinning by Gas, Air, or Water.

(A) Vertical Section of the thing to be projected or "turned" by retropulsion; (B) Projectile; or Water, Gas, or Air; (C) chamber containing force. On setting free this force in C, the charge B is sent out a long way, and the vessel A a short way. Or, this can be reversed. The Arrows indicate direction of motion. No motion takes place from 2 and 4 as the force is balanced equally.

the heavy object (the gun or cannon) a short way backwards. A "catherine wheel," and a rocket in fireworks, are examples of this backward motion, curvilinearly, and the wheel too, illustrates the top principle. There is a group of aquatic animals, consisting of the higher marine mollusca, to which *Octopus*, *Sepia*, *Eledone*, *Nautilus*, and others, belong, and also the water-breathing larva of one insect — the dragon-fly, *Libellula* — all of which swim by means of this internal unbalanced pressure, or recoil. Steam vessels have been driven on this plan.

Of course, the biggest top of all with which we have any personal experience, or, at least, the largest we are permitted to touch, is the great globe upon which we live, the centrifugal force of the motion of which has increased gradually its equatorial diameter. And if it did not whirl rapidly, both on its own axis and round the sun, and if the sun, moon, and earth were not restrained and kept in order by the same great and wonderful law as that which governs the spinning of a boy's top, annihilation of all things would instantly follow. Thus, the immense size of the earth causes its gravity or power to draw all things smaller than itself, to itself, and this power is so enormous, that if it were not for the opposite force given by its motion round its axis, nothing could move from its surface. And this is a frictionless motion, because there is no spindle, and nothing to rub against, outside the limit of our atmosphere. So it cannot stop. Or, in other

words, the centripetal force is balanced by the centrifugal force, and thus we can move about as we know we can do. Then, again, the still more enormous size of the sun would draw the earth to it with a great crash, if the centrifugal force of the earth, by its whirling round the sun, did not, in accordance with the same law, enable it to keep at a safe distance. And the moon is governed in her course, in turn, by the same law—and so, indeed, are all the heavenly bodies—the whole are controlled by precisely the same guidance as that which rules a spinning-top.

DEEP SEA LIFE.

By P. Herbert Carpenter, M.A.,

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THE earliest known instance of living animals being brought up from great depths in the ocean occurred in the Arctic expedition of Captain (afterwards Sir John) Ross in 1818. Some tube-forming worms, imbedded in a soft greenish mud, were obtained by the sounding line from a depth of nearly 1,000 fathoms; and a large Medusa-head starfish (*Asterophyton*) was entangled on the line at the 800 fathoms mark. On another occasion also, when a sounding was being taken in 1,050 fathoms, a small starfish was found attached to the line, below the point marking 800 fathoms. Several years later, systematic dredging was carried on in the Ægean Sea by the late Professor Edward Forbes, with the following results. He found an abundant fauna in the littoral zone, *i.e.*, at depths less than 50 fathoms; a diminishing fauna down to 100 fathoms; and below this a rapidly diminishing fauna down to 250 or 300 fathoms, and then a zero, no life at all. This depth limit, 300 fathoms, was supposed by Forbes to be the greatest depth at which animal life could exist in other seas besides the Mediterranean. He thought that life beneath the waves was always confined to a narrow border round the land; that plants were almost entirely absent below 100 fathoms, and animals scarce; while those that did exist were believed by him to represent those groups only which are the most simple in their plan of construction. The sea bottom at 300 fathoms was regarded by him as a desolate waste, its physical conditions being such as to preclude the possibility of the existence of living beings. Forbes's generalisation has since been shown to be perfectly true with respect to the Ægean, and indeed for the Mediterranean as a whole, parts of which are over 2,000 fathoms deep; but the Mediterranean is an inland sea, and presents some very exceptional characters, which cause it to be comparatively untenanted by animal life. In the open ocean the case is very different, as we shall see presently. Owing to his high authority on questions of this nature, Forbes's opinion was very generally adopted, alike by zoologists, physical geographers, and geologists; but it was soon shown that his views were not altogether sound, for the dredgings carried on in Sir James Ross's Antarctic Expedition, at depths of from 270 to 400 fathoms, yielded evidence of a great abundance and variety of animal life between these limits; and despite Forbes's dictum, Sir James maintained—and he was not alone in his belief—that "from however great a depth we may be able to bring up the mud and stones of the bed of the ocean, we shall find them teeming with animal life." How far this opinion has been borne out by facts will appear as we proceed. In June, 1845, Mr. Henry Goodsir, one of the Assistant Surgeons of Sir John Franklin's ill-fated expedition, dredged several different types of animal life at a depth of 300 fathoms in Davis Strait; and in the following year Captain Spratt, R.N., obtained living shell-fish from a depth of 310 fathoms in the Mediterranean itself, at a spot 40 miles east of Malta. Like Sir James Ross he "believed animal life to exist much lower, although the general character of the Ægean is to limit it to 300 fathoms."

About this time also the Swedish expedition to Spitzbergen, under Dr. Otto Torell, obtained a large and varied collection of invertebrate animals from a depth of 1,400 fathoms; but although these and other facts led a few isolated naturalists to believe in a full development of animal life at considerable depths in the ocean, it was very long before this doctrine commanded anything like a general assent.

During the series of telegraph soundings carried on in the North Atlantic in the year 1860 by H.M.S. *Bulldog*, the vexed question of deep sea life received much attention from Dr. Wallich. On one occasion the sounding line brought up a cluster of

brittle-stars attached to a portion of it which had lain on the bottom at a depth of 1,260 fathoms, and globigerinæ were found in their stomachs, together with other matters. Other animals were obtained from various depths down to 1,900 fathoms. Putting all these and other facts together, Dr. Wallich was led to the conclusion that animal life of an abundant and varied character existed at the bottom of the sea at depths which were generally supposed to be nearly or quite devoid of life; that the deep sea has its own special fauna, and has always had it in ages past; and hence that many fossiliferous strata, hitherto regarded as having been deposited in shallow water, may really have been deposited at considerable depths. Unfortunately there was one defective link in Dr. Wallich's chain of evidence. We have *now* no sort of doubt but that the brittle-stars which came up "convulsively embracing" a portion of the sounding line had been living on the bottom; but owing to the condition of knowledge—or, rather, want of knowledge—and prejudice at that time, their irregular mode of appearance left a loophole for scepticism. Had they only come up in the dredge, it would have been to find themselves famous. They would at once have achieved immortality as furnishing the first absolute proof of the existence of highly organised animals at depths exceeding 1,000 fathoms. Such a proof *was* obtained in the same year (1860), although, singularly enough, not by a professed naturalist. The cable of the Mediterranean Telegraph Company between Sardinia and Bona, on the coast of Africa, failed completely, and the first 40 miles of the Sardinian end were taken up for repair. The engineer directing the operations, Mr. Fleeming Jenkin, —now Professor of Engineering in the University of Edinburgh—found much coral and many other marine animals attached to parts of these 40 miles of cable, which had been submerged to a depth of 1,200 or 1,500 fathoms. The collection included shell-fish, tube-worms, sea-squirts (Ascidians), sponges, and polyzoa. Some of these animals had previously been considered very rare, or had been altogether unknown; whilst others were only known in a fossil state as belonging to the fauna of the later Tertiary deposits of the Mediterranean basin. Mr. Jenkin placed specimens of the animals which he had himself taken from the cable, with notes as to their respective depths, in the hands of Professor Allman, for determination; and he subsequently gave an interesting account of his proceedings at a meeting of the Institution of Civil Engineers. Some other portions of the cable were examined by M. Alphonse Milne-Edwards, who read a paper, describing the animals attached to them, before the Academy of Sciences in Paris. He laid great stress on the value of this observation as a solution of the vexed question of the existence of animal life at depths of the sea greatly below the "zero" of Edward Forbes. There could of course be no doubt as to the real depth from which the animals were obtained, and some of them, such as the corals and polyzoa, must have become attached to it when young, and have grown to maturity in the position in which they were found. This observation of Mr. Jenkin's, therefore, must be considered as having afforded the first absolute proof of the existence of highly-organised animals at depths in the ocean exceeding 1,000 fathoms.

During the last twenty years the attention of naturalists has been strongly directed to the question of deep sea life, and the importance and interest attaching to its solution have been recognised by the Governments of many of the European countries and by that of the United States. The earliest systematic work in deep sea exploration was carried on by Professor G. O. Sars, an inspector of fisheries under the Norwegian Government, who took advantage of the opportunities afforded by his occupation to dredge down to 450 fathoms on some parts of the coast of Norway and among the Loffoten Islands. No less than forty-two different species were found at 450 fathoms, while from the zone between this depth and 250 fathoms a total of 427 species was obtained. In the year 1868 Count de Pourtales commenced a most fruitful series of deep sea explorations by means of the dredge, in connection with the regular soundings carried on in the Gulf Stream by the United States Coast Survey, under Professor Pierce. Pourtales dredged down to 500 fathoms along a line between Florida and Cuba, and found echinoderms, corals, crustacea, worms, and mollusca: "in fact, a *fauna* as plentifully represented as along the most populous of our [American] marine shore fauna."

This promising start has been well followed up, scarcely a year passing without more or less dredging being carried on in the Gulf Stream by Pourtales, Stimpson, and others; while in 1871 the United States war steamer *Hassler* was placed at the disposal of the late Professor Louis Agassiz for a voyage of exploration round the coasts of America, from Boston to San Francisco; and, again, in the winters of 1877–8 and 1878–9 very

extensive dredging operations were carried on by Mr. Alexander Agassiz in the United States steamer *Blake*, in the Straits of Florida, Gulf of Mexico, and the eastern part of the Caribbean Sea. These explorations are only second in interest and importance to those carried on by our own Government during the same period, and the results of the one series gain greatly in value from the way in which they complete and extend those of the other. Our own systematic deep sea work began in the same year (1868) as that of our American fellow-workers. The *Lightning*, a small surveying ship, furnished with all the necessary appliances for dredging and temperature sounding, left Stornoway, in the Lewis, on August 11th, under the scientific charge of Dr. W. B. Carpenter and Professor (now Sir) Wyville Thomson. The weather was very unfavourable, and in five weeks only ten days were available for dredging in the open ocean, and only on half of these did the depth exceed 500 fathoms. On the last available working day it reached 650 fathoms. Nevertheless, the work of the *Lightning*, limited though it was, yielded most valuable results. Not only was it shown that animal life was varied and abundant, represented by all the invertebrate groups, down to a depth of 650 fathoms, but it was also shown that instead of the deep sea having a uniform temperature of 39° Fahr., there might be two distinct climates at the same depth within a few miles of each other: the one Arctic, with a temperature below the freezing point of fresh water (32° Fahr.), and the other with a temperature 15° higher. It was also shown that this was due to the movements, in opposite directions, of great masses of water at these different temperatures, maintaining by this means a remarkable system of oceanic circulation, and yet keeping so distinct from one another that an hour's sail would be enabled to pass from the extreme of heat to the extreme of cold. The *Lightning* dredgings, few as they were, and limited as was the area explored, revealed the fact that a large proportion of the forms living at previously unexplored depths belong to species hitherto unknown; and that while some are specifically identical with Tertiary forms supposed to be extinct, others are more closely related to types which had flourished in the Cretaceous period.

The results of the *Lightning* dredgings, briefly described above, were of such importance as to create a great desire for more extended investigations, which were made at greater depths and over a larger area, in the two following years, by H.M.S. *Porcupine*. In 1869 deep sea exploration was carried on over the area explored by the *Lightning* in the previous year (between the north of Scotland and the Färoe Islands), and also along the Atlantic coasts of Scotland and Ireland from Rockall to Cape Clear, and, lastly, still farther south, in the very deep water (2,500 fathoms) at the northern extremity of the Bay of Biscay. In 1870 the area explored was extended to the southward as far as the Straits of Gibraltar, while much work was also done in the Mediterranean basin. In this year, too, Mr. Marshall Hall, with an interest in science which is not too common among yachtsmen, devoted his yacht *Norna* to dredging along the coasts of Spain and Portugal down to a depth of 800 fathoms. The work of this cruise proved to be of great value and interest, as it supplemented that of the *Porcupine*, which not only confirmed the results gained by the *Lightning* two years previously, but extended them very considerably, proving that the bottom of the Atlantic at all depths down to 2,500 fathoms possesses an abundant and characteristic invertebrate fauna.

In the Mediterranean, on the other hand, the conditions are singularly unfavourable to life at great depths, the bottom below a few hundred fathoms being nearly devoid of life; although, as pointed out in a previous paper,* the temperature never falls below 54° Fahr., even when the depth reaches 2,000 fathoms. This great contrast between the faunas of the Mediterranean and Atlantic at the same depths, seems to be due to the fact that all the deeper parts of the Mediterranean are covered by a deposit of exceedingly fine mud, which is brought down by the Rhone, Nile, and other rivers, is dispersed by surface currents, and gradually subsides to the bottom. The turbidity of the bottom water which is thus caused is very unfavourable to animal life. All marine animals breathe the air dissolved in the water which comes in contact either with the general outer surface of their bodies or with special prolongations of it, that are known as gills; but if this water be charged with a number of very fine particles, the deposition of them upon the respiratory surface will interfere with its proper action. Oyster-beds, for example, cannot be established in situations to which fine mud is brought by any current. Corals, again, will not flourish near the mouth of a river, as they become choked by the sediment which it brings down; while the *Challenger* dredgings have shown that an admixture of river or shore mud with the ordinary deep

* "Science for All," Vol. III., pp. 76—83.

sea deposits is usually unfavourable to the development of a rich fauna, and the number of groups represented on a bottom of such a character is accordingly small. In this respect the Mediterranean basin differs very considerably from that of the Atlantic outside, the conditions of its deeper portions being very unfavourable to life. Hence, although Edward Forbes's generalisations which were deduced from his observations in the Ægean are true, not only for the Ægean, but for the whole of the Mediterranean basin, they do not hold good for the great oceanic basins, where life is found at all depths down to 4,000 fathoms.

The distribution of living beings has no depth-limit, but animals of all the marine invertebrate classes, and probably fishes also, exist over the whole ocean-bed. Although life is thus universally extended, it seems to be generally the rule, though not necessarily always so, that the number of species and of individuals diminishes below a certain depth, and that, at the same time, their size usually decreases, though this is not always the case. Thus, for example, the two deepest dredgings of the *Challenger* in the Atlantic, 3,875 fms. on a bottom of grey ooze, and 3,150 fms. on the red clay, yielded nothing but a few foraminifera; and a haul in 3,000 fms. in the Pacific, on a red clay bottom, brought up a few sponges and alcyonarians. But though the fauna is poor and stunted at these very great depths, shell-fish, worms, and star-fishes are fairly well represented at 2,500 fms.; and at still lesser depths, down about as far as 2,000 fms. there is a considerably varied "abyssal fauna."

Depth, however, is not the only condition which affects the distribution of animal life on the sea-bed; it also depends in a very marked degree upon the nature of the bottom, or upon conditions which modify this. Life is very scarce over the area of red clay, which is the most unproductive of all the deep sea deposits, its fauna consisting chiefly of worms and other shell-less animals. According to Sir Wyville Thomson, "this comparative sterility depends, no doubt, to a great degree upon the absence of carbonate of lime, but not entirely so; for the most sterile regions of the whole sea are the mortar-like lime deposits which form the slopes of coral reefs and islands. There appears to be something in the state of aggregation of the lime in the globigerina shells, and its intimate union with organic matter, which renders the globigerina-ooze a medium peculiarly favourable to the development of the higher forms of life; the stomachs of the more highly organised animals living in it or on its surface are always full of the fresher foraminiferal shells, from which they undoubtedly derive not only material for the calcification of their tests, but nitrogenous matter for assimilation likewise."

The particular kind of animal life existing on any one part of the sea-bottom also depends to a very great extent upon temperature. Nowhere is the temperature so low as actually to prevent the existence of life. In fact, there are many forms which are known as "Arctic," from their occurring most abundantly and most fully developed in the seas of high latitudes. Such, for example, is the beautiful large feather-star of the Greenland and Spitzbergen seas. The individuals of this species which have been dredged off Halifax and in the "cold area" of the North Atlantic are nothing like as large as those which occur farther north. On the other hand, cold may dwarf the fauna and limit the number and variety of its forms. Thus in the same "cold area" the common twelve-rayed star-fish, which is about the size of a pudding-plate in the British seas, is dwarfed down to about the size of a crown-piece. It is a matter of peculiar interest to see how such low temperatures affect forms with which we are perfectly familiar; because then we get the clue to the same influence operating through very long periods of time in reducing such a form as the pear-encrinite (*Apiocrinus*) of the Bradford Clay to the little *Rhizocrinus* (Fig. 1), which is so very widely scattered over the Atlantic sea-bed. The *Apiocrinidæ* attained their maximum of development in the Jurassic or Oolitic period, and are represented in the chalk by a type known as *Bourguetticrinus*, which is far smaller than the Bradford Clay species, and shows many other symptoms of degeneracy. *Rhizocrinus* is a closely similar type, but still more degraded, and it now lives on a cold bottom; whereas the Jurassic seas certainly, and the Cretaceous seas probably, were warmer than the bottom of the Atlantic at the present time. On the whole, except at very extreme depths, it is found that the conditions of the deep sea bed are not only such as to admit of the existence of animal life, but also to allow an extended distribution of animals high up in the zoological series, and closely related to some of those characteristic of shallower water; so that in this case the entire change of external conditions—namely, enormous pressure, utter darkness, and a difference in the chemical and physical conditions of the water and in the proportions of its contained gases—does not seem to influence animal life to any great extent.

Although animal life, as represented by the higher groups, is scattered, and by no means abundant at extreme depths, yet many of the abyssal forms have a very wide and perhaps even a universal distribution. The abyssal fauna is remarkably uniform, and although it contains representatives of all the principal marine invertebrates, the relative proportions in which these occur are peculiar. All classes of shell-fish, crabs, and worms are, on the whole, scarce, while echinoderms and sponges greatly preponderate. The families which are specially characteristic of the abyssal fauna, and are also most nearly related to extinct types, are very widely distributed, such as the siliceous sponges with six-rayed spicules (*Hexactinellidæ*, Fig. 2), the stalked crinoids like *Rhizocrinus* (Fig. 1), and other "sea-lilies" (Fig. 3), and certain sea-urchins, especially those which have a flexible test instead of a shell of immovable plates (Fig. 4). On the whole, they are more abundant, larger, and more fully developed in the Antarctic Ocean and in the great ocean of the water-hemisphere generally than they are in the Atlantic and Pacific. In many cases this uniformity is not limited to families, or even to genera, for species of urchins, crinoids, and shells are common to both the European and the American basins of the North Atlantic, while some few also occur in the Southern Sea. Others find their nearest allies not so much in species from shallower waters as in the inhabitants of seas of former geological periods, having, for example, a much closer relation to fossils from the chalk than to recent types previously known to us. Some, indeed, belong to groups of animals which were supposed to have become extinct with the close of the Mesozoic period of geological time; though the number of such "resuscitated" types which have rewarded deep sea explorations is not so great as was expected.

The remains of radiolarians are found in all the deep sea deposits, usually in very direct proportion to the numbers occurring on the surface and in intermediate waters. Foraminiferal shells fallen from above are also universally distributed, and living forms are very generally present, but they differ from those which are found at and near the surface chiefly in having sandy tests or calcareous shells, which are not pierced like that of *Globigerina* (Fig. 1, p. 79) for the exit of "pseudopodia." Sponges extend to all depths, the *Hexactinellidæ* (Fig. 2) being the most numerous and the most characteristic of the abyssal fauna. The same or very similar forms are found abundantly down to depths of 1,000 fms. along the coasts of Portugal and Brazil, while some species are apparently cosmopolitan. The hydrozoa are not very fully represented at great depths, though gigantic individuals were

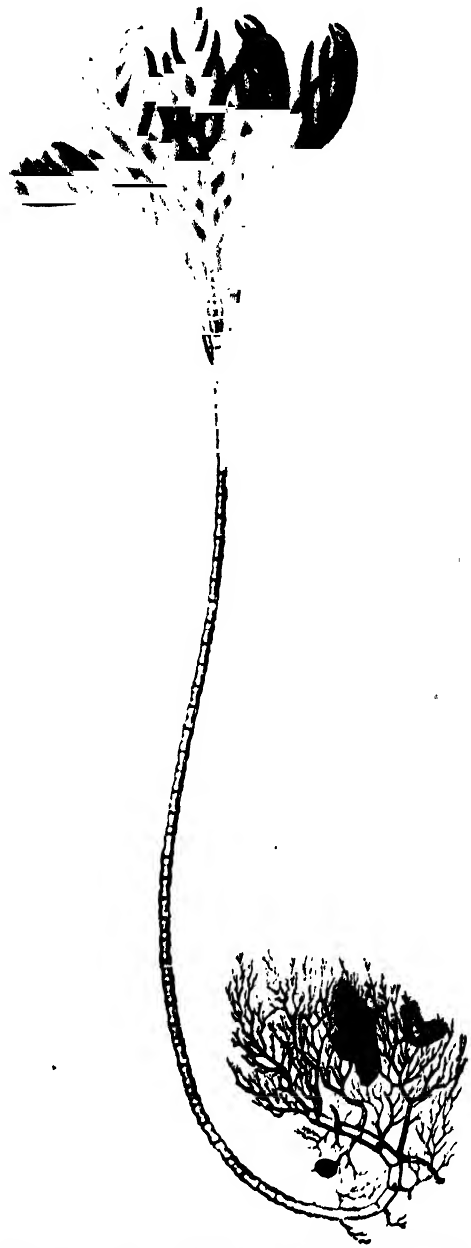


Fig. 1.—Rhizocrinus Loffotensis. One and a half times the natural size. (*After Sir Wyville Thomson.*)

dredged in the North Pacific at depths of 1,875 fms. and 2,900 fms., with a stem 6 feet long and a head measuring 12 or 15 inches across the crown of extended tentacles. Among the actinozoa, corals

are not abundant in deep water, though one species extends practically through all depths ranging from 30 fms. to 2,000 fms. Certain forms of sea-pens also go down to great depths, while the "clustered sea-*ibellularia*) appears occasionally, usually

2.—Holtenia Carpenteri. A "Hexactinellid" Sponge from the North Atlantic. (*After Sir Wyville Thomson.*)

in nearly the deepest dredgings, and is represented by two or three closely-allied species (Fig. 5).

Among the echinoderms the sand or brittle-stars are prominent members of the deep sea fauna, several species coming up from the greatest depths, while the ordinary star-fishes abound at all the more moderate depths. The sea-urchins are numerous and of great interest in their palæontological aspect, from the relations of many of them to fossils of the later M sozoic beds. The stalked crinoids or sea-lilies a e the most interesting of the deep sea echinoderms, but are comparatively few in number. The largest of them belong to the *Pentacrinidæ* (Fig. 3), a family which is abundantly represented in the Lias. They do not usually extend to the greatest depths, as do *Rhizocrinus* (Fig. 1) and two allied genera which are the last survivors of the large and important family *Apiocrinidæ.* The holothurians, or sea-cucumbers, like the brittle-stars, are very generally distributed, occurring down to the greatest depths. Worms are rare in deep water, though in one or two localities they seem to be almost the only inhabitants of the red clay, making their tube-like houses of a peculiar gritty matter which the clay contains in small quantity.

The various orders of Crustacea form a most interesting and important element in the deep sea fauna. The stalked cirripedes (barnacles) and shrimps are very generally distributed, but the crabs are confined almost exclusively to comparatively shallow water. Shell-fish do not enter largely into the fauna of the deep sea, but some species, usually small and apparently stunted, are widely though sparsely distributed. Fishes, though not abundant, appear to be universally present near the bottom of the deep sea, nearly every haul of the *Challenger's* trawl bringing up one or more.

One of the most curious points in connection with the distribution of life on the sea-bed is the very great difference in the faunas of the "warm" and the "cold" areas of the North Atlantic. It has already been mentioned that one of the results of the *Lightning* expedition was the discovery of two distinct submarine climates at the same depth, and within a few miles of one another, in that part of the North Atlantic which lies between the north of Scotland and the Färoe Islands. The average bottom temperature of the "cold area" is a little below the freezing point of fresh water (32° Fahr.), though it sometimes falls as much as $2\frac{1}{2}°$ lower. This low temperature is due to a direct movement of cold water from the Arctic Ocean into the North

Sea. A rapid current sweeps round the south of Spitzbergen and greatly reduces the temperature of the North Sea, while a part of it moves into the channel between the Färoe Islands and the north

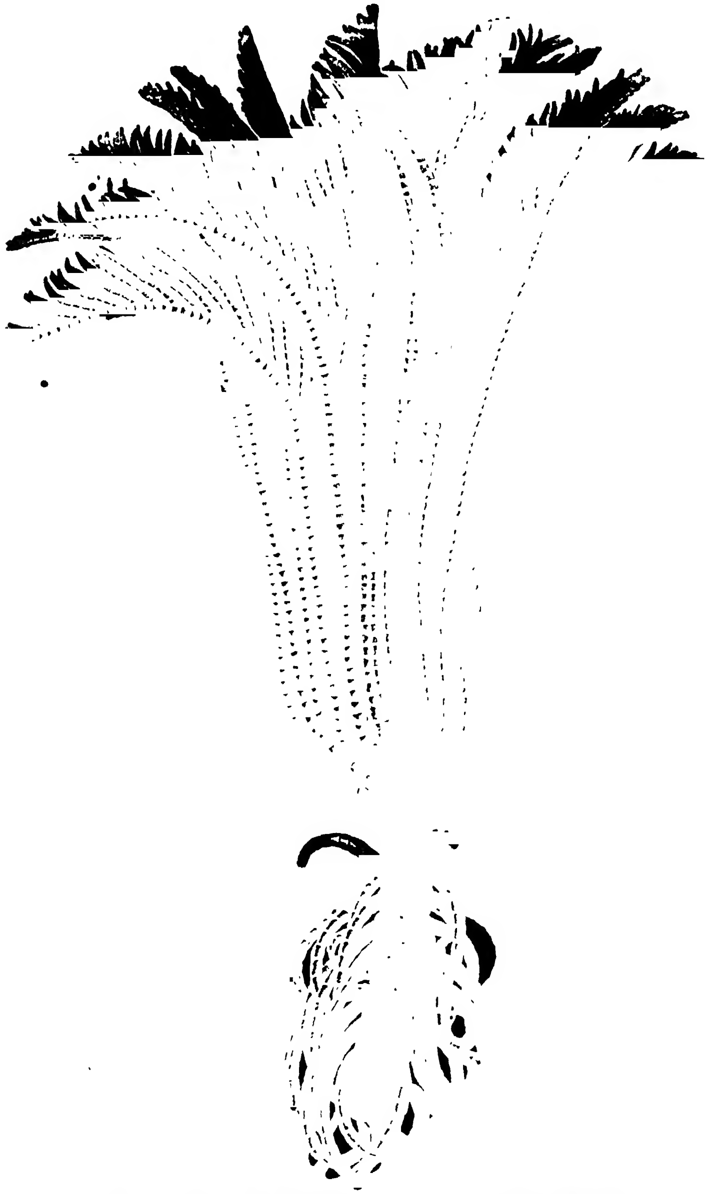


Fig. 3.—Pentacrinus Maclearanus. A Sea-lily. Slightly enlarged. (*After Sir Wyville Thomson.*)

of Scotland which was explored by the *Lightning* and *Porcupine*. At the western opening of the channel between the Färoe banks and the Hebrides, the Arctic current moves down the slope which forms the eastern margin of the great North Atlantic basin. Here it meets the similar currents which have come southward along the east coasts of Iceland and of Greenland, and it unites with them in spreading over the deepest portions of the North Atlantic basin, where they meet a corresponding indraught of Antarctic water, so that the temperature of the basin is very considerably lowered. It never, however, falls quite so low as in the "cold area" of the Färoe channel. But owing to this fact of Arctic conditions being continuous (in a broad sense) throughout the greater depths of the North Atlantic, a large number of the inhabitants of the cold area are common to the deep water off Rockall and as far south as the coast of Portugal. But besides these generally distributed forms, the fauna of the Färoe channel includes others [such as the large crustaceans and sea-spiders (Fig. 6), and some of the star-fishes], which are not only generally characteristic of cold climates, but especially so of that part of the Arctic province which is represented by the seas of Spitzbergen Greenland, and the Loffoten Islands.

In the "warm area" and wherever the bottom is covered with globigerina-ooze, calcareous foraminifera predominate, and many of the common types have remarkably large representatives, which are considerably larger than any forms previously known from the temperate regions. Some of the Cristellarians have their shells encrusted with sand-grains bound together by a calcareous ---- while true arenaceous forms also occur. But the latter kind, in which the ordinary calcareous shell is replaced by a case or test composed of cemented sand-grains, are almost the only foraminifera of the cold area, where the bottom consists only of sand

and small stones; and these arenaceous forms, although abundant in their several localities, are very limited in their geographical range. The most common types consist of beaded tubes, about an inch long and one-eighth of an inch in diameter (*Botellina*), and the large-chambered *Lituolæ;* but with the exception of these arenaceous types the foraminifera of the cold area are not remarkable either for number or for variety, and as compared with their extraordinary abundance in the warm

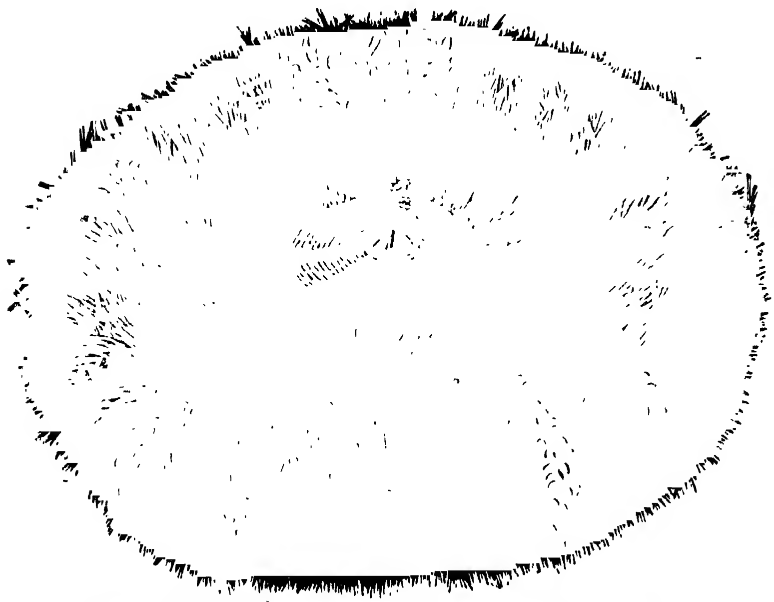


Fig. 4.—Calveria hystrix. A Sea-urchin with a flexible test. Two-thirds the natural size. (*After Sir Wyville Thomson.*)

area, are rather "conspicuous by their absence." The sponges of the warm area are very characteristic. Most of them have flinty skeletons and belong to the group of the *Hexactinellidæ,* or sponges with six-rayed spicules (Fig. 2). Their spicules consist of a primary axis of variable length, which at one point is crossed at right angles by four secondary rays. Sponges are also abundant in the cold area, but the types represented are mostly quite distinct from those of the warm area as well as very diverse *inter se.* One type belonging to the *Coralliospongiæ* (in which the spicules consist of a shaft with three diverging rays at one end) is especially common. It is one of the most characteristic inhabitants of the cold area, seeming to cover hundreds of square miles of the sea-bed, and growing as a kind of bush or shrub, so as to clothe the bottom like heather on a moor. It has a firm branching axis of a pale sea-green colour rising from a spreading root, and composed of a continuous horny substance. It is clothed with a soft bark of the pale yellow sarcodic substance of the sponge, which is covered with pores and rises here and there into elevations, perforated by the large exhalent apertures or "oscula."* Both axis and bark are crowded with flinty spicules.

Although many of the echinoderms of the cold area are common to the warm area, the general appearance of the two echinoderm faunas is very different, and that of the cold area contains a number of additional and very striking forms, chief among them being a heart-urchin of extraordinary interest. In fact, its remarkable richness in echinoderms, both in number and variety, is undoubtedly the chief characteristic of the fauna of the cold area. They are, however, chiefly of Boreal or even Arctic types, and those of the characteristic southern forms which occur are far smaller than usual, some of the star-fishes having only one-third their ordinary size. Amongst the more northern forms are nearly all those described by the Scandinavian naturalists as inhabiting the seas of Norway and Greenland. Thus, the most common form in the locality known as the "Haaf" (the deep sea fishing-ground on the Shetland plateau) was a tiny sea-urchin (*Echinus Norvegicus*), three-quarters of an inch in diameter, which had previously been considered as a great rarity. The *Porcupine,* however, obtained it literally by thousands, 20,000 or more coming up at a single haul of the dredge. The large *Antedon Eschrichtii,* again, is remarkably abundant in the cold area. It is one of the two Arctic species of feather-stars, having been dredged in the Spitzbergen and Kara Seas, Davis' Strait, round Iceland, and lastly in the Arctic current off Halifax by the *Challenger.* Not one, however, was obtained in the warm area, the crinoids of which are all members of the stalked division of the group. The best-known one is the small *Rhizocrinus Loffotensis* (Fig. 1), already referred

* "Science for All," Vol. I., p. 59, Figs. 5, 6.

to us of extreme interest, owing to its being a representative—though only a small and degraded one—of the great family of the *Apiocrinidæ*, which were so abundant in the Jurassic seas. The large pear-encrinites of the Bradford Clay are common fossils in museums, and reduced representatives of the type occur fossil in the chalk, so that the discovery

Fig. 5.—Umbellularia Groenlandica. The Clustered Sea-polype. Natural size. (*After Sir Wyville Thomson.*)

in 1864 by G. O. Sars of the still more reduced *Rhizocrinus* at a depth of 300 fathoms off the Loffoten Islands was of extraordinary interest. This type has also been obtained by the American dredgers on the other side of the Atlantic, and two other members of the same family have since been discovered. Fragments of *Rhizocrinus* were dredged in the cold area, but no living specimen was obtained, although the current in the Färoe channel comes directly from the seas of the Loffoten Islands, where it abounds.

With one or two exceptions, the characteristic Arctic echinoderms do not occur in the warm area, but it is inhabited by some very peculiar sea-urchins with flexible "tests," composed of overlapping plates (Fig. 4), and quite unlike the ordinary urchins, in which the plates meet edge to edge and abut against one another so as to form a continuous rigid shell. These flexible urchins recall a very singular fossil from the white chalk which had been supposed to be extinct like the stalked crinoids, and the discovery of the persistence of this type until recent times is of the highest interest and importance.

The crustacea of the cold area are distinctly Arctic, many of them belonging to the fauna of Spitzbergen, while others are characteristic Norwegian forms, most of them reaching a very great size. This is especially the case with the sea-spiders, specimens of which, 5 inches in diameter, were very plentiful in the cold area (Fig. 6). Crustacea are numerous in the warm area, but the gigantic Arctic forms are entirely unrepresented, and are replaced by other types of a more southern nature, some of which are familiar Mediterranean forms.

Shell-fish are much more abundant in the warm than in the cold area. In the latter they do not, as usual, constitute the principal results of a dredging haul, but are quite subordinate, as regards both number and variety, to the groups already mentioned. Many species are common to both areas, the difference between their molluscan faunas being by no means so great as that shown in other groups. On the whole, however, the fauna of the cold area is decidedly characteristic, although many of its most distinctive species are common to the deep water of the warm area whenever its temperature sinks below about 37° Fahr.

The "bottom" of the cold area is mostly coarse sand and gravel. On the Scottish side of the channel the gravel consists chiefly of the *débris* of the Laurentian gneiss and other metamorphic rocks of the north of Scotland, and the "Old Red Sandstone" beds of Caithness and Orkney. On the Färoe side of the channel, however, the sand and pebbles are chiefly basaltic. This difference shows itself very distinctly in the colour and composition of the worm-tubes, and in the tests of the arenaceous foraminifera. The pebbles are all rounded, and their variable size and the roughness of the gravel in different places indicate a certain amount of movement of material along the sea-bed. On the other hand, the "bottom" of the warm area is the globigerina-ooze, the presence of which is sharply bounded

by the limits of this area. At its borders the composition of the ooze is modified by an admixture of the sand characteristic of the cold area, which is especially distinguished by the presence of particles of augite and other minerals having an undoubted volcanic origin.

The cold area, as already mentioned, has sharply-restricted boundaries; but the globigerina-ooze occupies an enormous extent of the North Atlantic sea-bed.* It covers the ridges and elevated plateaus below 400 fathoms, and occupies a belt at depths down to 2,000 fathoms round the shores, outside the line of shore deposits. All this area, however, cannot be considered as a continuation of the warm area of the *Lightning* and *Porcupine* expeditions. The whole 500 fathoms or 600 fathoms of water down to the bottom at the mouth of the Färoe channel corresponds only to a surface layer of similar depth in the main Atlantic basin. Here the uppermost 700 fathoms or 800 fathoms are in all cases actually "warm," being a portion of a great northward set of warm water, of which the Gulf Stream is so important a part. Where, however, the depth greatly exceeds 800 fathoms there is a mass of cold water beneath, sinking slowly to near the freezing point (32° Fahr.), altogether irrespective of the nature of the bottom. Thus between Madeira and Cape St. Vincent the *Challenger* found the temperature to be frequently as low as 35° at depths of 2,000 fathoms or more, although the bottom was the same globigerina-ooze as that dredged farther north from a depth of only 500 fathoms, with a bottom temperature 10° higher.

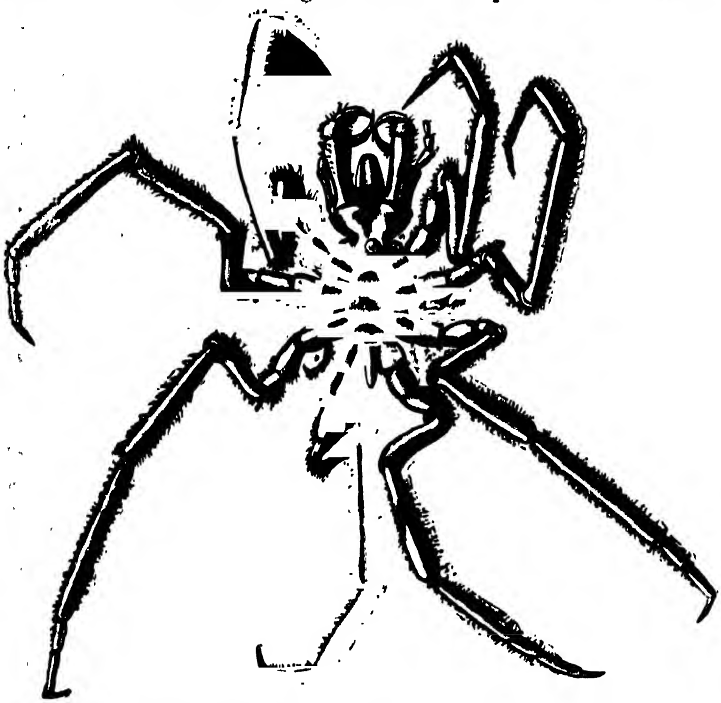


Fig. 6.—Nymphon abyssorum. The Sea-spider. Slightly enlarged. (After Sir Wyville Thomson.)

The "bottom" or habitation of the fauna, therefore, is only warm (*i.e.*, 40° Fahr. and upwards) when the depth is not greater than 800 fathoms, and in such a case only can the term "warm area" be correctly applied. Such are the conditions off the Färoe Islands, and it is this which makes the contrast of the warm and cold areas so marked in that region. This contrast is of remarkable interest to the geologist, for it has been shown how, at the same depth and on the same geological horizon, two distinct deposits may be taking place within a few miles of one another, both covering large areas of the sea-bottom, but differing alike in their mineral characters and in the nature of their inhabitants. Were they raised into "dry land," the one deposit would be found to be a coarse sandstone, including fragments of older rocks, and possessing a characteristic fauna of an Arctic type. The other would be a calcareous rock essentially like chalk, and would contain a great variety of animal remains of a totally different type from the fossils of the sandstone, several of them belonging to a temperate rather than to an Arctic fauna. The differences between these two have been shown to depend upon differences in the bottom temperature of the various parts of the sea in which the two deposits are being laid down. It has been suggested that similar causes—climatic differences depending upon deep ocean-currents—may have produced the remarkable contrasts between the faunas of different areas of the same geological formation with which geologists and palæontologists are so familiar.

* "Science for All," Vol. III., p. 81.

JUPITER.

By W. F. Denning, F.R.A.S.

When a man first practically engages in astronomical work, he naturally becomes inquisitive to know the best class of observation suited to the capacities of his telescope. The firmament exhibits a multitude of objects, from the resplendent sun to the faintest nebula; and looking at the clear nocturnal sky whensoever and wheresover he will, it will be found to display variety enough and beauty enough to satisfy the most fastidious observer. Groups of stars showing a remarkable diversity of configuration and magnitude are more or less profusely scattered over the whole celestial vault, and interspersed with nebulæ of various forms and degrees of condensation. The brighter stars here and there emitting their scintillations, and the major planets shining with a grander, steadier lustre, enabling them to be distinguished from the sparkling light of the stars, combine to attract the attention of the observer. The planets, it must be admitted, offer the most interesting features for telescopic examination, for the best instruments exhibit the fixed stars merely as luminous points, incapable of amplification by the highest magnifiers; while the planets are at once resolved into large globes of well-defined outline, displaying a variety of markings upon their surfaces. This is the case particularly in regard to Mars, Jupiter, and Saturn, but has no reference to the myriads of minor planets grouped between the orbits of Mars and Jupiter, which, as telescopic objects, certainly have no claim to merit, since their extremely small dimensions render the details of their surfaces utterly beyond our reach. But attractive as are the aspects of some of the chief planetary members of the solar system, there is no doubt that the moon, of all objects, is eminently the one of greatest interest, exhibiting, as she does, a mass of permanent detail, never shrouded in atmospheric vapours, and maintaining a perfectly clear and serene appearance, enabling it to be sharply defined in a telescope. Her mountain ranges, crater-chains, and other formations, with those curious luminous streaks or radiations extending over certain regions of her surface, render the lunar scenery as imposing as it is varied, and when represented in a good instrument, the view of our satellite is one that may be contemplated for a long time without flagging interest. On the sun we perceive that the condition of the visible surface is wholly different. Interposing coloured glass to cut off the intensity of the solar rays, we are enabled to conveniently scan the brilliant disc and to distinguish there many dark and bright spots of irregular and rapidly changing forms, situated in the sun's luminous atmosphere, and giving evidence of the occurrence of vast disturbances. Thus, considered as telescopic objects the sun and moon are totally dissimilar. The evanescent, ever-varying markings in the sun's bright envelope are in striking contrast to the persistent forms ranged over the face of the moon. In other words, while the phenomena apparent on the sun are purely atmospheric in origin and transient in nature, the markings displayed on the moon are part of her real surface, and of permanent character.

Of the planetary members of the solar system Jupiter offers in many respects the most attractive features for examination. He forms a distinct system of his own, and is remarkable for his great magnitude, and for the rapidity of his motions. Not only does he present an interesting object for the naked eye, shining with a lustre not much inferior to Venus, but as an object for telescopic scrutiny his appearance is magnificent, exceeding in extent of detail that of any other planet, and more readily distinguished with instruments of moderate power. To the naked eye he far excels the lustre of Sirius, and Mars is seldom comparable with him. Venus, however, justly claims superiority as the most brilliant luminary of her class, though her position as a morning or evening star never reaches 50° distance from the sun; hence she is always seen more or less in the twilight, and often enveloped in the fog and smoke floating about at low altitudes. Jupiter, on the other hand, at opposition, continues visible throughout the whole night, and therefore the circumstances of his apparition are more favourable than in the case of Venus. When Jupiter is thus situated in the winter months, he attains considerable elevation, for his position in the zodiac has nearly the same altitude as that attained by the sun at midsummer; and in the clear, frosty nights of that season, when the moon is absent, this planet is the most lucid object in the heavens. Could we behold Venus under the same propitious auspices, high in the midnight sky, her apparent brilliancy would be greatly enhanced, far surpassing her lustre as we have been accustomed

to notice it, as she precedes or follows the sun at her western or eastern elongations.

Jupiter arrives at opposition once in about thirteen months, and is then admirably well placed for investigation. The application of a very small telescope will reveal the globular form of the planet, and dismiss the false rays commonly originated by the eye, and show the satellites as faintly discernible stars ranged in a line on either side. Possibly, too, a faint indication of the belts may be apparent in the form of several dark parallel lines crossing the planet's equator, but they will be traced with some difficulty, and the observer will scarcely be able to glimpse any of the details so readily distinguished in powerful instruments. But the planet himself, shining as a small bright globe, and beside him his retinue of four attendant satellites, compose, it will be admitted, a spectacle of attractive rarity, displaying before our eyes a perfect miniature system in which are exemplified the same laws by which the sun and planets are governed and regulated. In fact, the jovian planet, with his minor orbs, is aptly suggestive of that great system of which he is one of the individual members, and in the motions and periods of his satellites are repeated the same rules which characterise the leading planets of the solar system. Thus even in a small glass the view of Jupiter affords a fitting object for contemplation, as giving an idea well within the compass of our vision of what is displayed in the more vast and wide arrangements of the sun and his circling planets.

With every increase of optical power the features of Jupiter and his moons become more plainly manifested. Many details which had wholly escaped recognition with inferior means, now come well into view, and may be submitted to careful inspection. The dusky streaks or belts upon the planet are resolved into well-defined bands of shading, exhibiting much variety in depth of tone, with here and there light spots and patches interspersed with darker markings. The number of these belts is sometimes very considerable. Near the equator there are usually two very distinct zones of shading, supplemented by outlying narrower bands, less conspicuous than those girding the equator. Farther towards the poles more of them appear, all running nearly parallel, and in such close juxtaposition as to be hardly separable. In the immediate polar regions the belts have apparently coalesced, forming caps of grey shading. Towards the central meridian of the planet the belts generally are more conspicuous, fading away upon the margin of the disc. Some observers have delineated them as abruptly terminating before reaching the limb, but they may always be followed up to the very edge of the planet, though often very faint there. Fig. 1 represents the appearance of the planet's disc as figured by the writer on March 7th, 1873, with a reflecting telescope of 10½ in. aperture, power 450.

Two darkish spots were seen, with adjoining light spaces, and the belt lying N. of the equa-

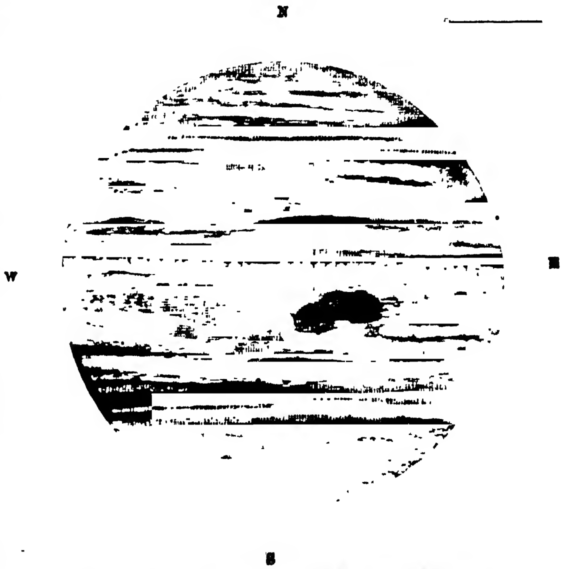


Fig. 1.—View of Jupiter's Belts, March 7, 1873, 7.40 p.m.

torial shadings was broken and curved downwards on the western side. The South polar shading was noted very dark, being nearly as conspicuous as the chief belts and far deeper than the North polar shading, which seemed comparatively faint.

Zucchi, at Rome, on May 17, 1630, was the first, according to Riccioli, to distinguish the belts on Jupiter. Though more difficult than the satellites, they are nevertheless sufficiently conspicuous for observation in small telescopes, and it is certain that they could not long remain undiscovered after the invention of that instrument. They are, however, of variable intensity, sometimes faint, at other times very dark and plain. Though subjected to many changes of form, yet they display some permanency in general appearance, while they exhibit nothing like the constancy of the markings on Mars. The forms of the jovian belts at ensuing oppositions of the planet, though sometimes fairly accordant, seldom show resemblances sufficiently close to allow the conjecture that the same forms are successively presented to view. Indeed, it is often

the case that the aspect of the surface at intervals of a few months wears a totally different appearance, and the obvious inference is that the markings are purely attributable to atmospheric disturbances, and in no way representative of the condition of the planet's real surface. It would seem that the longitudinal stripes or belts by which he is completely invested are produced by air-currents similar to our trade winds, but more strongly marked and regular than those which prevail on the earth, because the diurnal velocity of Jupiter's surface is far greater. The dusky belts of the planet are probably referable to zones of clear atmosphere, for land is less highly reflective than cloud. Indeed, it would appear from many trustworthy observations that the atmosphere of Jupiter is constantly charged with dense volumes of cloud, concealing the actual surface of the planet from view, and allowing it to be exposed only in the equatorial regions and in the vicinity of the dark spots. But the clouds of Jupiter, though liable to considerable variations, yet maintain a certain permanency of general form, distinguishable during several successive months, and are evidently far less changeable than the vapours of our terrestrial atmosphere.

Spots and irregular markings of very uncertain character frequently occur in the belts, and are sometimes unusually permanent. A very dark spot was detected as early as 1664, by Hooke, and in the following year by Cassini; and it is supposed to have remained in existence until 1715, for in the interval a similar appearance was noticed on the disc by several observers. Mädler detected two black spots on November 3rd, 1834, and they continued visible until April 18th, 1835, but during the interval the belt on which they were situated had entirely disappeared, the spots, however, retaining their full distinctness. After April the planet could not be examined, as it approached conjunction with the sun; but in the following August, when observations were renewed the spots had altogether vanished. In 1843 another large black spot made its appearance, and in 1858 two oblong dark markings were noted as interesting objects. Small luminous specks are sometimes manifest on the planet, resembling satellites in transit, and occasionally grouped together in rather considerable numbers. They appear to have been first detected in 1849. On October 25th, 1857, a cluster of minute luminous spots, eleven in number, were seen in the southern hemisphere of Jupiter, and in the following year a similar appearance was manifested nearer to the equator and in a *bright* belt. Apart from these singular markings, the belts display many curious forms, though the general aspect is that of well-defined regular streaks with a remarkable parallelism of direction. Curved and slanting streaks are occasionally perceived, and the belts are sometimes broken. A wavy appearance has also been delineated, and the chief equatorial belts have exhibited a series of oval forms which, according to Webb, "have the aspect of a girdle of luminous egg-shaped clouds surrounding the globe." These objects were especially noticeable in 1868 and the few ensuing years, when the conspicuous colouring of the planet's equatorial region also attracted considerable attention, and gave rise to the suspicion of periodical recurrences.

But the cloud-scenery of Jupiter has never, perhaps, been submitted to such general observation and discussion, as during the favourable appearance of the planet in the early autumn of 1879. A very remarkable spot or cloud, of oval form, and showing intense ruddy colouring, attracted notice early in July, 1878, and it has displayed such conspicuous features and permanency as to receive the special attention accorded to an important phenomenon. It is uncertain whether the object can be considered an entirely new feature on Jupiter, for we have many records of dark elliptical spots having been detected upon his disc; but it is admitted that if it existed a few years ago it must have been considerably fainter, and perhaps merely in process of formation. Oval markings were seen traversing the disc during the years 1868 and 1869; and it will be an interesting point to determine by a comparison of the observations whether the present spot occupies the same position on the planet. The interest centred in the subject will certainly lead to a full discussion of the phenomena which have been recorded now and in past times of dark figures appearing and disappearing amidst the equatorial bands of Jupiter, and observers will apply themselves more sedulously to the examination of the wonderful scenery he offers to view. Carefully executed sketches of his appearance, made every year, might reveal the fact that his principal features are less liable to variations than is commonly assumed, and evidence might be furnished of the re-appearance of the same objects after certain intervals. Markings upon the real globe of the planet may be hidden several years together by the interposition of cloud-masses above them, for it is certain that the density and constancy of terrestrial clouds bear no comparison with what is

exemplified in a more extreme degree in the jovian atmosphere. And it must be remembered that being immeasurably superior to the earth in point of size, the phenomena occurring on Jupiter are on a scale proportionately more vast and commensurate with his huge dimensions and rapid motions.

The oval rose-tinted object to which we have been referring has been described and figured by many observers. Its position on the disc of Jupiter is slightly south of a broad band lying above, and south of the equator. The magnitude of the spot is enormous, for in the autumn of 1879 its major axis extended over an area of more than 24,000 miles, according to the independent estimates of two observers. Professor Pritchett, of Glasgow, Missouri, who was the first to call special attention to the spot, wrote in August, 1879, that it was "situated on *very nearly* the same part of the planet's surface as it was fourteen months ago. The only appreciable difference in its appearance now and last year is the very perceptible elongation of the major axis of the oval, and the shortening of the minor. The longer axis is precisely parallel to the equator of Jupiter. From a large number of micrometer measures I find the mean major axis to be 14″·56, and the minor 3″·85." Thus the length of this singular object is nearly four times its breadth, and the significant facts mentioned by observers, that it is in process of lengthening out, and that it runs parallel with the planet's equator, greatly favour the idea that it will ultimately form a new belt on Jupiter. The observations show it to have a decided tendency in this direction. If the spot is to be explained on the assumption of a gigantic opening in the cloud-system of Jupiter, then its further rapid distension longitudinally appears a fair conjecture. The very rapid axial rotation of the planet, which is performed in about 9 hrs. 55½ mins., gives an enormous velocity to the surface; for while objects on the earth's equator travel at the rate of 17 miles per minute, those on Jupiter traverse 467 miles in the same interval, or in the proportion of about 27 to 1. This tremendous speed must have an effect upon the planet's atmosphere, probably occasioning currents of great force, and giving rise to the dark and bright streak-zones alternating on the planet's surface. The apparition of a dark oval form on Jupiter, and its palpable lengthening out in conformity with the direction of the belts, suggest the idea of a new belt in course of production, and the future behaviour of the spot, if it continues in sight, will form a very interesting object of inquiry. That the swift axial rotation of this planet affects the condition and appearance of his atmosphere is

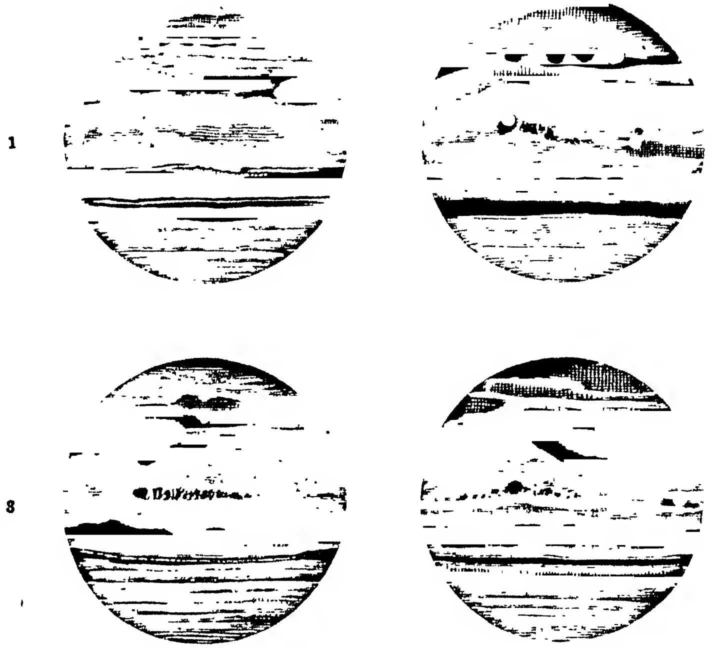


Fig. 2.—Jupiter in 1879. (1) August 21st, 12.30 a.m.: (2) August 29th, 12.5 a.m.; (3) September 3rd, 10.15 p.m.; (4) September 7th, 12.0 midnight. Scale, 1 inch = 30″.

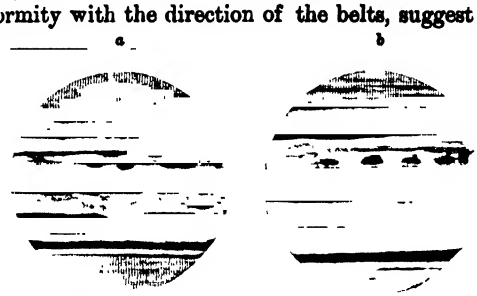


Fig. 3.—Jupiter's Belts and Spots. (a) January 3rd, 1880, 4.45 p.m.; (b) January 5th, 1880, 4.23 p.m.

rendered more probable by the fact that on and near the equator, where the motion is greatest, the belts exhibit considerable regularity in their parallelism, but on the more remote parts of the disc, towards the poles, where the velocity decreases, the streaks are less decided, and they often show deviations from a parallel course.

The preceding figures represent the planet's inverted appearance as seen by Mr. G. T. Gwilliam, using a reflecting telescope of 6½ in. aperture, power 200 (Fig. 2). The red spot was first seen by him on August 21st, 1879, and on August 29th it appeared to have become longer, being estimated as fully 12″ long and 5″ broad. The two dark spots situated on the equatorial belt were the first and second satellites in transit. On September 3rd the red spot was again in view, lying over a gap in the great southern equatorial shading. A large white spot was observed almost due north of the red spot, followed by several smaller ones of fleecy appearance, and these again followed by dark spots on the central zone. On September 7th the third satellite was in transit over the disc. The white spots were again discerned, also the conspicuous red marking, now almost at the apparent centre of the planet.

In 1868, and at each favourable re-appearance of Jupiter during the few ensuing years, many dark spots were perceived on his surface. The writer at Bristol made a series of observations of the planet during the last three months of 1868 and early in January, 1869, and obtained thirty-nine sketches of the appearances presented by the belts in a 4¼ in. refracting telescope. A belt just south of the equatorial bright zone exhibited some abnormal appearances of light and shade, and sometimes seemed, when definition was very good, as it often was at about the time of sunset, to possess a wavy or undulatory aspect. Two views of the planet are here reproduced (Fig. 3), in which several dusky spots are shown, but as observed on successive nights they apparently varied in intensity of shading; so that, while sometimes recorded as faint, they were occasionally described as very dark and plain, and scarcely less noticeable than the shadows of the satellites when projected on the disc. The best views of these phenomena are obtained early in the evening, before the lustre of the planet has attained its full power. The disc shines with so much brilliancy in the absence of twilight that the delicate features are almost wholly obliterated in the glare. Considering his enormous distance from the sun, his brilliancy is rather surprising; for, compared with the light of Mars, it has been found that the apparent splendour of Jupiter far exceeds a proportionate degree in the comparison, and the conclusion seems inevitable that the exterior physical characteristics of Mars are such as more readily absorb the solar rays than Jupiter does. It is calculated that the intensity of sunlight at the distance of Jupiter is about thirteen times less than at Mars, and were the reflective properties of their surfaces equal, the visible lustre of the latter planet ought considerably to exceed that of Jupiter. In fact, though the apparent area of the jovian planet greatly exceeds that of his smaller rival, yet at his vast distance from the sun the solar light is so considerably weakened that Mars should (with equal reflective power) exhibit the greatest brilliancy. But we may probably find the explanation in the fact that while the atmosphere of Jupiter is loaded with highly reflective clouds, the condition of Mars is very different, displaying a clearer aspect, free from any rapidly-varying phenomena from which could be inferred the existence of cloud-laden strata above his surface.

In point of size, no other planet except Saturn is comparable with Jupiter. The dimensions of the earth are vastly inferior. In Fig. 4 let E represent the form of the earth, then J is the relative size of

Fig. 4.—Relative Size of Jupiter (J) and the Earth (E).

Jupiter. His real equatorial diameter is about 88,000 miles. The compression at the poles is very considerable, exceeding that of any other planet. Several determinations of this value give $\frac{1}{17}$. The apparent diameter varies largely between opposition and conjunction, being as much as 51″ in the former position, and only 31″ in the latter, while at mean distance the best measures give 38″.

Jupiter being situated some 475 millions of miles away from the sun, it is obvious that, at a spot so remote, the solar diameter will be very small as compared with that seen from the earth. In Fig. 5, if the circle E represent the apparent size of the sun as observed by us, then the small circle J shows

interesting of the varied and frequent phenomena presented by the jovian satellites. The first recorded instance of an observation of this kind was in 1658, by one of Campani's old and unwieldy refractors. The moons, as they enter upon the planet's eastern limb, appear as bright spots, but as they approach mid-transit they are lost in the luminous background until, nearing the opposite margin, they re-appear as before. Sometimes a satellite may be followed throughout its entire course across the disc, especially when its position coincides with one of the dark belts; and even this condition is not always necessary, for the satellites now and then appear as dark spots traversing their primary. Occasionally they will be very faint in individual instances; in fact, their relative brightness is very inconsistent. It is considered that they always present the same hemisphere to their primary—in this respect offering an analogy to our own moon—and, therefore, different sides are turned towards us, so that, in effect, we are able to discover some features of the jovian satellites which are wholly invisible from the surface of Jupiter. That spots of very decided intensity are sometimes shown by the moons is obvious by the fluctuations in their comparative lustre, and by the fact that when in transit they have been observed as dark objects, nearly as deep in tone as their shadows, crossing at the same time. Dawes and Secchi distinguished these markings with sufficient success to delineate them in the case of the third satellite, as in Fig. 6; but the objects are so distant, and the phenomena so minute, as to

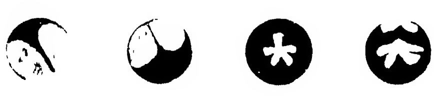


Fig. 6.—Markings on Jupiter's Third Satellite.

form a crucial test of excellency of eye and telescope.

At rare intervals it may happen that a powerful instrument, directed towards Jupiter, will fail to reveal the ordinary satellites shining by his side. To an observer unaware of the explanation, and not expecting so unique a spectacle, the view must be very astonishing, especially if he has been accustomed to look at the planet and at the moons invariably ranged in a line about him. Yet there can be no mistake; here is Jupiter with his usual belt-scenery, but not the ghost of a satellite. The sky on either side of the planet, in which their orbits were wont to extend, is dark and utterly void of any luminous objects, while the orb of the planet stands out boldly—an isolated sphere on the opaque background of space. There can be only one explanation of so startling and weird an apparition. The moons are all rendered temporarily invisible by a curious combination of phenomena: one is eclipsed in the shadow cast by the planet, another is occulted by his globe, while the two remaining are in front of the planet; and, examining the belts with a critical glance, the observer will perceive the dark shadows of the latter, and perhaps the moons themselves, wending their way along the disc. Continuing to watch the planet, he will perceive their several re-appearances until, an hour or two after the first observation, the planet will have regained his customary aspect. Several instances are recorded in which Jupiter has been seen without his satellites; the last occasion was on the evening of August 21, 1867, when the writer witnessed the phenomenon with a 4¼ inch refracting telescope. The view of Jupiter, in its inverted form, is represented in Fig. 7.

The five black dots projected on the belts south

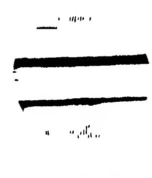


Fig. 7.—Jupiter without his Satellites, August 21, 1867, 10.30 p.m.

of the equator were the shadows of the first, third, and fourth satellites, and two of the satellites themselves rendered perceptible by dark spots on their surfaces. The second satellite was eclipsed at the same time. In fact, during the period of 1¾ hours (10 h. 4 m. to 11 h. 49 m.) the planet appeared to be utterly devoid of satellites. This singular phenomenon, though of considerable rarity, had been witnessed on several previous dates, viz., on November 2, 1681 (O.S.), by Molyneux; by W. Herschel, on May 23, 1802; by Wallis, on April 15, 1826; and by Dawes, on September 27, 1843, who also observed the repetition of the phenomenon in August, 1867.

Apart from the mere fact that the satellites are of considerable interest as telescopic objects, and from the circumstance that their first discovery formed a memorable incident, as upholding the Copernican system of the universe, they subserve other important purposes; for the eclipses afford a readily

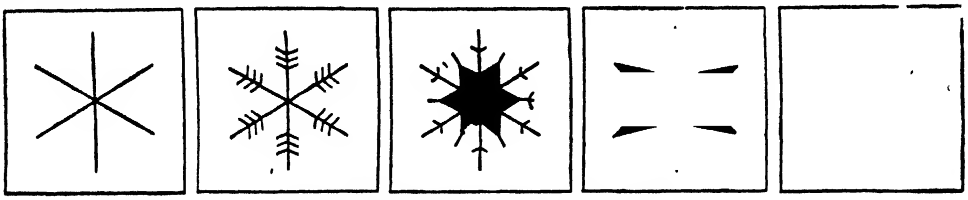
available method of determining the longitude; and it must be remembered that the progressive motion of light was also first ascertained by the same means. In finding the longitude, an instantaneous occurrence, perceptible at the same moment at two distant places, may be utilised in deriving the difference in longitude of those places, by a comparison of the exact times shown by a chronometer at each station; the difference being converted into degrees and minutes, is equal to the discordance in longitude. But the eclipses of Jupiter's satellites, though visible simultaneously at every station, having the planet above its horizon, and capable of being accurately predicted, yet present difficulties in the solution of this problem, for the observations have usually to be made at sea with instruments rendered almost unserviceable by the motion of the ship; and, moreover, the eclipses are not instantaneous, so that two observers will sometimes disagree as to time; but, in cases where absolute accuracy can be dispensed with, these phenomena are often eligible. The progressive motion of light became evident on comparing together the predicted and the observed times of the eclipses. It was found that they occurred about 16 minutes earlier when Jupiter occupies that region of his orbit nearest to the earth than when on the farthest side; and the differences noted at intermediate points exhibited great regularity, which clearly indicated their origin in the varying distance separating Jupiter from the earth, and admitted the final discovery, that light travelled at the velocity of about 190,000 miles per second, inasmuch as it occupied 16¼ minutes in traversing the diameter of the earth's orbit.

The satellites apparently present few anomalous points for future elucidation. We are already conversant with the chief phenomena to which their motions give rise, and can discern enough of their minute discs to warrant the conjecture that dark irregular markings exist upon them. But though much has been learned of the satellites, it must be conceded that our knowledge of the surface of Jupiter is extremely limited. The vast changes in the forms of the belts are a mystery, and we have little or no evidence to show the character of these changes, whether they are regularly recurrent after certain intervals, or whether they take place indiscriminately, without regard to time or position. All that has been learned of the visible aspect of the Jovian surface is that it exhibits great variety of detail, which appears constantly in an agitated condition, though some of the peculiarities undoubtedly show signs of permanency. The aspect of the planet, if critically watched and delineated during many successive years, would possibly give appearances indicative of the nature of the vast disturbances of which our telescopes have already revealed the traces. The formation of the belts, and their ultimate dispersion, might be recorded throughout their several stages, and a certain periodicity might be found to influence their apparitions, both in regard to form and colour. The surface of Jupiter comes readily within the scope of moderately powerful glasses, and it will be matter for congratulation, as likely to yield results both of interest and value, if observers make this planet a special object of study during coming years. The systematic employment of a telescope is much to be recommended. Many observers use their instruments in the most erratic manner, upon every object within range. After a careless, cursory glance in one direction, the glass is turned towards the opposite point of the heavens, to inspect another object with equal haste and indecision. This is continued during the whole evening, at the end of which the observer is left where he began, with very dim conceptions of what he has seen, though truly there has been plenty of variety in his work. It is far better for a man to devote himself to the cautious and complete examination of a single object, thoroughly noting every visible detail, then comparing it with what has been previously recorded, and pondering over it, than to employ his telescope without method or purpose upon every class of object displayed in the sky. The range is so wide, the appearances so numerous and diversified, that he is most likely to succeed who selects a special branch or object of inquiry, and follows it sedulously year after year. A man coming fresh to the subject, and simply entering upon the work as a pleasurable occupation of leisure hours, can well be excused any systematic endeavours resulting in the monotony likely to ensue from the pursuit of one and the same object, because his end is already attained. Indeed, the indiscriminate use of a telescope cannot always be condemned as profitless, for an observer who has been assiduously devoting himself to a special line of inquiry will, as he finds it ultimately growing wearisome, experience renewed interest in his favourite study by temporarily entering new fields and exploring them for a time, finally coming back to his particular branch with refreshed energy.

HOW A SNOW-FLAKE IS FORMED.

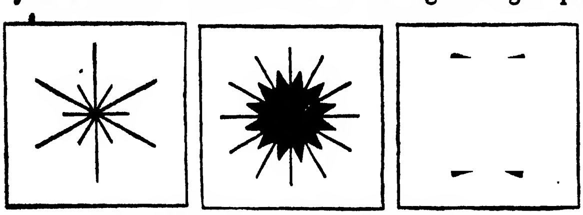
By Robert James Mann, M.D., F.R.C.S., F.R.A.S., etc.,
Ex-President of the Meteorological Society.

IN a recent paper* hoar-frost was spoken of as frozen dew; as dew-drops crystallised out into ice-needles by the marshalling force of molecular



Figs. 1, 2, 3, 4, 5.—Snow Crystals. (*After Glaisher.*)

aggregation, when this is to a large extent freed from the antagonistic influence of segregating repulsion. In following out this line of investigation, it will now be by no means difficult to perceive that snow stands in the same relation to rain which hoar-frost holds in regard to dew. It is moisture frozen into ice at the instant that it is condensed out of its transparent and invisible state in the air. But in the case of the snow, the frozen deposit is formed during free suspension in the air, and without any interference from contact with solid radiating surfaces such as is experienced in the production of hoar-frost. The solid particles are consequently grouped into regular geometrical shapes, which are designed by the inherent directive forces of the gathering



Figs. 6, 7, 8.—Snow Crystals. (*After Glaisher.*)

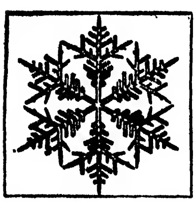
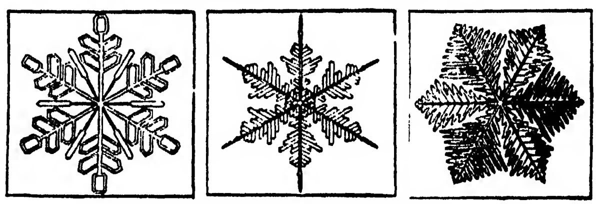


Fig. 9.—Snow Crystal. (*After Glaisher.*)

molecules. Snow forms in the air whenever there is as much aqueous vapour as two and a half grains in each cubic foot, and whenever the temperature is depressed as low as 32° Fahr. Some part of the superfluous moisture, over and above that which can still be sustained in the invisible state, is then set free, and allowed to gather into visible masslets which, as the temperature is below that of freezing water, present themselves as spicules of ice, instead of as droplets of water. But when water is slowly converted into ice without any extraneous or interfe ing strain being brought to bear upon its particles, these are first built up into the shape of a needle, or bar, and six of these bars are then grouped round a common



Figs. 10, 11, 12.—Snow Crystals. (*After Glaisher.*)

centre, like the spokes of a wheel, with angular intervals of 60° between each contiguous pair of spokes. In Fig. 1, this six-spoked crystal of frozen water is represented in its simplest and most rudimentary form. When snow falls gently in still air, six-rayed spangles, exactly like the one sketched in the figure, are very often seen.

Such simple forms as this primary one are not, however, the only kind of crystalline aggregations that are observed in gently-falling snow. If the deposit of the frozen molecules is more rapid and more copious, additions of a secondary kind are made to the primary rays. In the first instance, short needles are added to the primary ones, branching out from them at the same angle of 60°, and producing a figure like that shown in Fig. 2. Then the primary rays broaden out by snowy wings, or films, attached along their side, as represented in Figs. 3 and 4, until at last these fuse themselves together into a flat hexagonal plate with six points and six sides (Fig. 5); all these peculiarities are common in falling snow. Sometimes a double system of radiation is planned, with intermediate

* "Science for All," Vol. III., p. 145.

short rays introduced between the longer primary ones, as in Fig. 6.

Compound forms are also found based upon this model by the filling in more or less of the interval contained between the rays, as instanced in Figs. 7 and 8. The secondary needles are occasionally further branched with tertiary spikelets, which are then also fixed on the same typical angle of 60°, as in Fig. 9.

An almost endless diversity of figures, indeed, is constructed as the rapidity of deposition varies, and as external relations and conditions are changed, but in all the same primary type of six rays and of hexagonal outline, which is the fundamental necessity of the crystallisation of freezing water, is observed. More than one thousand quite distinct kinds of snow crystals have been enumerated and described by various observers. One hundred and fifty-one were noticed during eight days in the months of February and March, in 1855, by Mr. Glaisher, and these have all been carefully drawn and engraved, and were printed in connection with a paper which was attached to the Report of the Council of the British Meteorological Society for that year, and which is one of the most interesting and valuable of the contributions on the subject of snow-crystals which have ever been made to Science. Figs. 10, 11, and 12, selected, with others of our diagrams, from this series, will serve to convey some notion of the complexity and beauty of the forms which snow crystals sometimes present.

The most usual condition in which these snow-crystals are deposited is that of narrow needles, all arranged in one plane, or of thin plates. But the aggregations of the gathering particles are sometimes made in a more solid form, and grow into compact prisms or hexagons. The needles occasionally bristle out all round from a central spherical nucleus. Most complicated and curious figures are sometimes composed by the super-position of two, or occasionally of even more, crystals upon each other. The most complicated traceries are generally produced during the prevalence of extreme degrees of cold. The lightness, regularity, and delicacy of the crystallised spangles is, in general terms, in proportion to the height of the atmosphere from which they descend, and to the opportunity that is afforded during the long descent for the molecular forces concerned in crystallisation to accomplish their work deliberately and without interruption. Very perfect snow-crystals are only met with in temperate climates upon rare opportunities, and at long intervals. But they are of very common occurrence in colder climates and more frigid latitudes. Mr. Glaisher's beautiful series of figures were secured during a few exceptionally lucky days of snowfall that occurred in the neighbourhood of London between the 8th of February, and the 10th of March, in the year 1855. They were represented as they appeared to magnifying lenses after they had been received gently upon chilled fragments of yellow glass. Snow lay upon the ground at this time uninterruptedly during six weeks. On the 21st of February the thermometers indicated a temperature of 20°, at the time when some of the most beautiful of the crystals were observed. The spangles were generally about a tenth part of an inch in diameter, but in some instances they measured as much as three-tenths of an inch across. In ordinary snow-flakes several different kinds of crystals are confusedly grouped, and partially fused together in consequence of their being whirled about and dashed against each other, as they descend through air strata of varying temperature. Under the most favourable circumstances the radiated crystals may be contemplated both growing, and diminishing and altering their forms. Many of the most remarkable figures are produced by the softening away of primary points and edges during incipient dissolution, and by the deposit of amorphous accretions upon the primary axes and lines of the crystals.

Very fine and lightly deposited snow occupies about twenty-four times as much space as water. The thickness of an ordinary fall of snow collected upon the ground generally represents about as much water as would lie in a tenth part of the same depth. Ten inches of snow, therefore, correspond with one inch of rain. The most accurate way, however, to estimate the quantity of snow that is contained in any fall, is to cut a round cake out of the deposit to its full depth by a cylinder of copper, or tin, of known diameter, and then to measure the water that is procured by melting that quantity of snow. This at once furnishes a ready means of comparing the fall of snow with rain-fall measured in a rain-gauge possessing a receiving funnel of the same diameter as the cylinder.

The pure white lustre of snow is due to the circumstance that all the elementary colours of light are blended together in the radiance that is thrown off from the surface of its crystals. It is quite possible to examine the individual crystals in such a way as to detect these several colours before they are mingled together to constitute the compound impression of whiteness upon the eye. The

snow is then clothed with all the varied hues of the rainbow. The soft whiteness of snow is also in some degree referable to the large quantity of air which is entangled amidst the frozen particles.

The formation of snow requires that the temperature of the air shall fall lower than the freezing-point of water. But a heavy snow-fall needs that the air shall be very moist as well as very cold. The simultaneous presence of these two conditions in the atmosphere does not occur very frequently in the northern hemisphere of the earth, and it is for this reason that heavy snow is so rarely experienced in the countries of Europe. Snow falls very heavily indeed, and often accumulates to enormous depths, on the western side of the continent of South America in latitudes not far exceeding the forty-third parallel, and therefore corresponding very nearly with the position of Rome in the northern hemisphere, because the air is there always heavily laden with moisture when it sinks to the freezing temperature. Snow is scarcely ever seen on the southern coast of Spain. It seldom presents itself on any of the low-lying valleys or plains of Greece, although it is commonly seen on the tops of the neighbouring mountains in the season of winter.

In all latitudes of the earth snow occurs at high elevations in the atmosphere, although it may not reach the ground in consequence of its being melted as it falls through the lower and warmer parts of the air (Fig. 13). Even in equinoctial regions of the earth it is occasionally formed at an elevation of 11,000 or 12,000 feet, and if there are mountains with tops reaching up as high as this, they catch the snow, instead of allowing it to fall to the warm lower regions where it can be melted. It is for this reason that there are mountains covered with snow all the year round in so many warm latitudes. Such mountains reach up into regions of the air where there is not warmth enough to melt all the snow that is deposited upon the summits. Snow lies unmelted all the year round at the level of the sea within fifteen degrees of the earth's poles: that is, in latitudes higher than 75°. The area of perpetual frost is, however, not included within an exact circle traced round the pole. In the northern hemisphere it extends a little farther from the pole in the direction of the Pacific Ocean than it does

Fig. 13.—Snow-flakes in the Higher Regions of the Atmosphere illuminated by Direct Sunshine.

towards the Atlantic, and about the meridian of Iceland. There is thus a somewhat irregular frost-cap, of something like 1,200 miles across, fixed over the poles of the earth. In advancing from the outer limit of this polar region of the earth towards lower and warmer latitudes, the position at which perpetual congelation occurs rises higher and higher into the air. In England it is above the tops of the highest mountains. In Switzerland it is found at a height a little less than 9,000 feet; very nearly one-half of Mont Blanc is for this reason perpetually snow-clad. Perpetual snow lies at an elevation of 9,000 feet on the Pyrenees, and at 9,500 on the Apennines and upon Etna. It is found at 14,000 feet on Ararat, at 15,800 on the equatorial Andes, and at 16,500 feet on some parts of the Himalayas. The accompanying view (Fig. 14) represents Mont Blanc and its associated peaks, with their covering of perpetual snow descending some 7,000 feet below the highest summits.

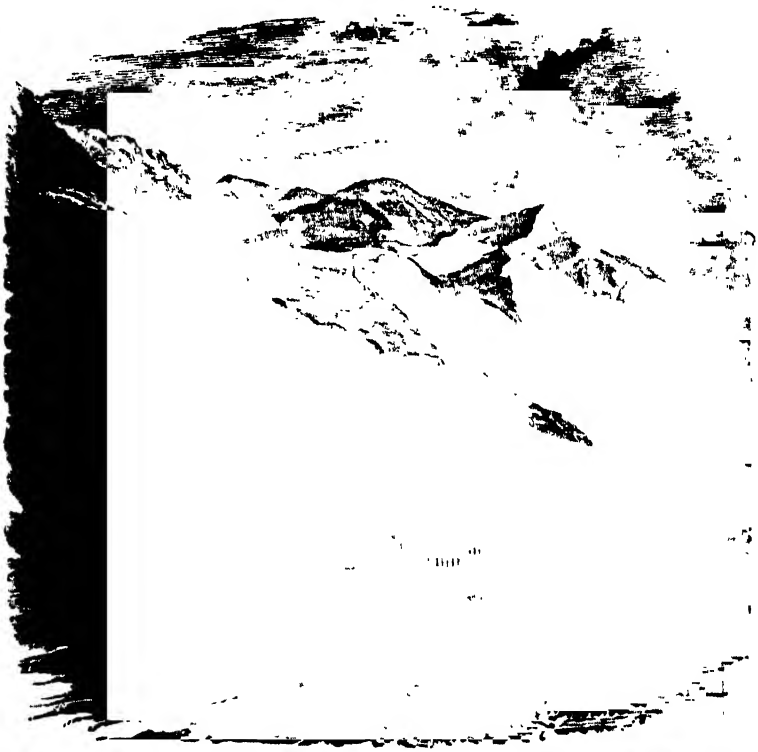


Fig. 14.—Mont Blanc and its attendant Mountains, with their Covering of perpetual Snow.

The snow, however, which lies in this way upon the tops of lofty mountains all the year round is perpetual only in a particular and limited sense. It is not everlasting snow. The phrase "eternal snow," which is occasionally used by the poets, is not scientifically correct. No snow is eternal or everlasting in the proper sense of these words. Snow is always present, but it is not the same snow. That which falls upon the highest summits of the mountains glides slowly down the grooves and valleys of their sides. In the illustration (Fig. 14) which represents the mountain system of Mont Blanc, snow-fringes, or rather ice-fringes, are seen hanging low down into the valley of Chamouni, which bounds this grand cluster towards the south. It is from amidst these that the vast ice-stream, which is known as the Mer-de-Glace, descends like a frozen river out of the heart of the snow-fields above. These descending streams of consolidated snow are spoken of as glaciers. They are composed of hard ice at their lower parts, and of vast gathering snow-beds above. The hard icy state of the frozen mass below is to some extent due to the compression to which it is there subjected. The snow clings to the rocky sides of the gorges and ravines with considerable tenacity, and it is accordingly squeezed by the weight of the masses pressing down from above. But although the first result of the pressure is to render the snow compact and hard, the ultimate result is of an entirely different character. When the pressure has increased to a very considerable extent, it softens even the hardest ice into a kind of yielding paste, which is pushed through the winding grooves and narrow gaps, and over resisting obstacles that stand in its path. As soon, however, as it is released from the severe pressure, the softened ice returns to its original hard consistence. It is by this instrumentality that the hard, rigid ice is forced through curving and rounding channels, and along alternately widening and narrowing beds. It becomes soft and plastic where it is compressed, but is brittle and easily worn into gaping fissures and chasms, wherever it is extended instead of being squeezed in. The "crevasses," or cracks, of glaciers are always found in those portions of the ice-stream where the frozen mass is freed from

direct pressure, and exposed instead to tensile strain, such as of necessity occurs in passing down steep declivities.

The first suggestion of this operation of the softening of ice under pressure was made by Professor Faraday in 1850, in consequence of his noticing that whenever two pieces of thawing ice are pressed closely together, they invariably freeze at the surfaces of contact into one continuous mass. As a matter of fact, the temperature at which water freezes is altered by strong pressure. Greater degrees of cold are required to convert it into the solid crystalline state when it is strongly compressed, than when it is free from such influence. Sir William Thomson has shown by direct experiments that if a mixture of ice and snow is very forcibly squeezed it becomes colder and colder as the pressure is augmented. The heat which is lost from the sensible state during this process is converted into the latent and insensible condition. But as it is so rendered latent, it is used in turning a small portion of the solid ice into liquid water. The water, however, is more incompressible than the ice; it is not, therefore, lowered in temperature to the same extent as the ice. There is, therefore ice which is colder than 32° in contact with water at the temperature of 32°. The consequence is that the water is immediately re-frozen by the chilling influence of the ice. Dr. Hooker* first proposed that this operation should be termed re-gelation, or re-freezing, and this very apt and expressive designation has since been generally adopted by scientific men. It is this peculiar property of ice of being softened and melted by pressure, and of immediately freezing hard again when the pressure is removed, which is brought into play in the familiar operation of making snowballs. The portions of snow which are squeezed together by the hand become moistened by the direct agency of the pressure, and then freeze together into a coherent mass when the pressure of the grasp is lessened. The snowball is, so to speak, a mimic glacier artificially manufactured.†

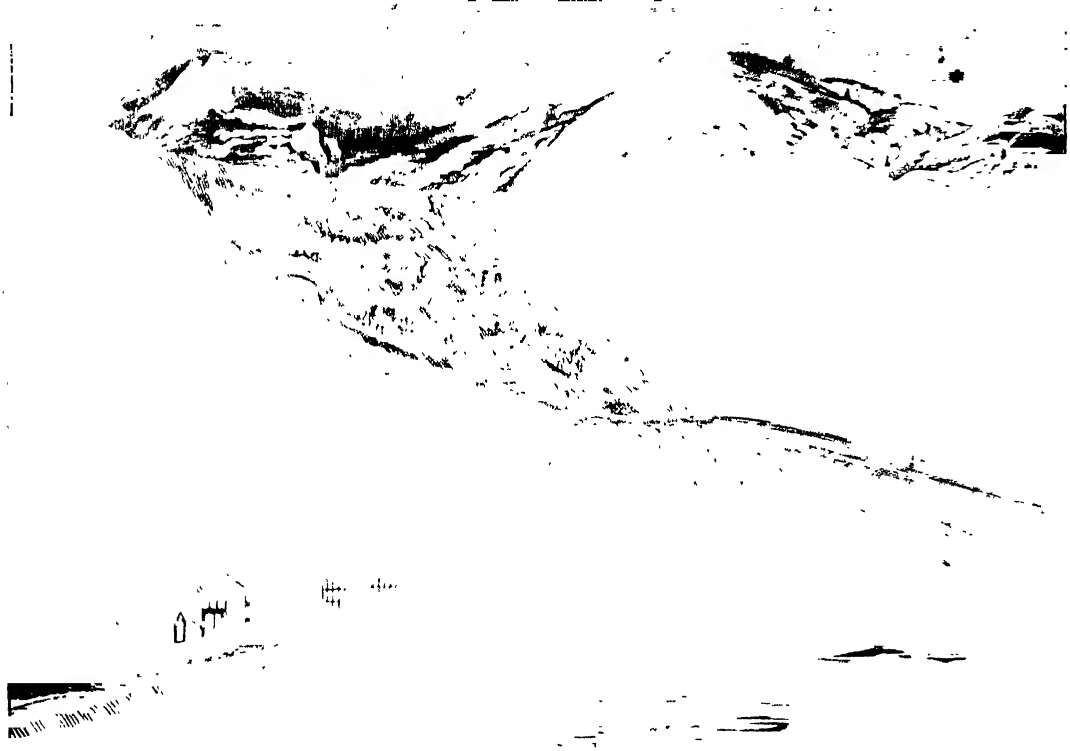


Fig. 15.—The lower Extremity of the Glacier of the Rhône, descending by the Side of the Furca Pass into the Head of the Valley of the Vallais, with the River issuing from it.

* Now Sir Joseph Dalton Hooker, Director of the Royal Gardens, Kew.

† See an interesting experiment illustrating this particular property of ice melting under pressure, illustrated in "Science for All," Vol. I., p. 32. Glaciers have been fully described in Vol. I., pp. 33—40; and Vol. II., pp. 181—187, and pp. 267

The lower extremities or toes of the glaciers melt away in the warm valleys which they finally reach, below, and are there turned into streams of running water, as fresh snow is heaped upon the heights above. The Arveiron, one of the feeders of the river Arve that joins the Rhône just below the Lake of Geneva, issues in this way from the lower end of the Mer-de-Glace. The Rhône itself takes its rise from another glacier of a similar kind, which pours its frozen mass down a steep descent by the side of the Furca pass, at the head of the Vallais (Fig. 15). The glacier masses which drape the sides of high mountains are thus always wasting below and increasing above, and the snow masses above are as continually sliding down to supply the consumption of ice that is taking place below. The rate at which the descent of the frozen mass is accomplished depends upon the rapidity of the slope, and the obstacles which it has to overcome in its route. But as a general rule it does not exceed ten or twelve inches in the day. In some notable instances this has been ascertained by direct measurement to be about the rate at which the ice of the glacier moves. Whenever the ice glides along a gentle descent not exceeding an inclination of three degrees, and with a fairly open and untrammelled course, it remains smooth and unbroken. But whenever it descends slopes that are considerably more abrupt, it tumbles over in a torrent of broken fragments, with huge cracks and chasms interspersed amongst them in the wildest confusion. The melting extremities of the glaciers of the Alps are generally found at an elevation of between 2,000 and 3,000 feet above the sea. Until recently, one of the glaciers of Grindelwald was the lowest amongst them, and reached quite into the close neighbourhood of the gardens and corn-fields of the valley. The Gorner glacier, which is one of the ice-streams that descend from Monte Rosa, terminates in a similar way near Zermatt, in a very grand form of ice-toe, projecting quite into a region of green vegetation. The lower end of the Rhône glacier represented in the last illustration, Fig. 15, is hemmed round with verdant herbage and bright flowers during the season of the Swiss summer.

The chief snow-fall upon the sides of lofty mountains necessarily occurs at, or within, an elevation of 9,000 feet above the sea. The average fall in the year at that elevation may be estimated at about forty feet of vertical depth. Upon the higher summits of very lofty mountains, such as Mont Blanc and Monte Rosa, very much less is precipitated, on account of the greater dryness of the air at those extreme elevations. The white caps of the snow-clad giants are principally preserved by the precipitation upon them of a kind of hoar-frost, partly condensed out of the clouds, and partly derived from the vapours that steam up to them from the large snow-fields below. The actual depth of snow upon the summit of such a mountain as Mont Blanc has not yet been ascertained, but it is very probable that it does not much exceed ten feet. On the lower slopes of such mountains, on the other hand, it often accumulates to a depth of many hundred feet. Cracks opened out into the ice of some of the larger glaciers have been sounded to a depth of 700 feet without reaching the bottom of the frozen mass.

The snow which is deposited upon the highest parts of lofty mountains is very fine and dry. It is a kind of snow-dust. This dryness is due to the rapidity with which every trace of free water escapes in these elevated and rare regions of the atmosphere. Immediately below the comparatively thin cap of dry snow the broad expanse of deep snow begins. But where the one passes into the other there are generally deep gaps or rents, called *Bergschrunde*, caused by the heavier accumulations below tearing themselves asunder from the lighter deposits above by the mere influence of weight. The surface of the snow on these broad and deep snow-fields assumes the state of small grains about the size of hempseed, which are ice within and snow without, and which are loosened asunder and partially melted by day, but frozen together into connected clusters at night. It is this granular surface-snow which constitutes the "fern" or "névé" of the Swiss mountains. In the lower part of the more massive accumulation water percolates through the upper porous mass, as the surface is melted by the sun, and this is then frozen into a foundation of firm, solid ice below. This subjacent ice-bed increases in thickness in the lower stretches of the glacier, until at last compact, solid ice only is found. It is probable that the compact ice of the interior of the large glaciers is always kept at a temperature of about 32° of Fahrenheit, and therefore in a state ready to undergo the process of regelation. The fractured masses which are tumbled down the more precipitous parts of the glacier bed are almost invariably frozen again afterwards into

—273, and therefore are only alluded to in this place in the most general way. The following paragraphs of this article, it will be observed, relate rather to the physical history of perpetual snow, than to the nature and motions of the great ice-rivers formed by it.

renewed continuity by the operation of this agency. To adventurous travellers climbing the snow-mountains, the ice-glacier appears to issue from the broad fields of granular snow, or névé.

Professor Tyndall has shown that even compact and solid ice is primarily formed out of six-rayed star-crystals, very nearly resembling those of snow, but with their angles intimately and closely interlaced together. By skilful employment of magnifying glasses, these can be seen forming in ice that is beginning to freeze, and they can also be traced, by a similar application of optical instruments, in clear dense ice that is just beginning to melt. The lightness of ice which enables it to swim upon water is partly due to the small portions of air which get entangled amidst the ice-crystals as these are grouped into geometrical forms in the act of freezing.

CORAL ISLANDS.

By Professor P. Martin Duncan, F.R.S., etc.

TO the west of the continent of South America lies the great sea desert; and especially westwards of Callao the ocean may be sailed over for weeks, without a trace of land being seen. A rolling sea, never less than 12,000 feet deep, and a blue sky with a blazing sun, are the daily and monotonous characteristics of some sixty degrees of longitude, or of one-sixth part of the circumference of the globe. At last a speck is seen in the distance, just above the surface of the sea, and as it is neared the waves are seen breaking on a glistening white shore, which has a background of dense dark foliage and some cocoa-nut trees. Behind, there is a still lake, called a lagoon, and it is environed by a ring of corresponding beach and wood. No mountain rises in the midst, and the surf thunders on to the "weather" shore, behind which the land rises a little sharply to the height of a dozen feet. To leeward there is less wave, and often a lane of water may be seen leading from the central lake through the encircling land to the open sea. The ship takes soundings as the land is approached, but the short, ordinary sounding-line gives no indication of bottom, even within a short distance of the broken water, out of which, rock may be seen emerging as the waves recoil. This circular ring of shore and wooded land, environing a placid lake and rising just above the surface, out of a profoundly deep sea, is a true coral island, or atoll (Figs. 1, 2).

Dana, who is always full of poetry in his descriptions, tells us that Marakei, one of the prettiest coral islands of the Pacific, "lies like a garland thrown upon the waters." It hardly deviates from the circular form, and the line of vegetation is unbroken; yet in one place there are indications of a former passage from the lagoon to the open sea. Another atoll or coral-island is triangular in outline, and its construction is to a certain extent explanatory of the manner in which the land arises from the sea. Thus Tari-Tari, or Pitt's Island, one of the Kingsmill group, has the side facing the south-east wooded, and there are spots of verdure also on the south-west. In this last-mentioned side there are three large entrances from the sea into the lagoon, which is extensive. Now the northern side is not land with wood, for what is called a reef is there, that is, a long coral rock just submerged at ebb-tide, which is scarcely visible from a ship's deck, except on account of the troubled water and the breaking waves on it. This is an incomplete atoll, for the northern side is still submerged, and changes have to occur there which have been undergone on the other sides; in fact, land has to be made on the submerged reef. In the smaller coral islands, when they are completed, the lake or lagoon "rests quietly within its circle of palms, hardly ruffled by the storms that madden the surrounding ocean" (Fig. 3). But in the southernmost island of this group, which is thirty-three miles long, the great lake is often rough, although the land and reefs act as breakwaters. In the direction of the wind, that is to say, on the eastern or windward side of the whole, there is land; but on the western side, to leeward, there is no land, and only a submerged reef, like that of the northern side of Pitt's Island. Hence the lagoon is not strictly environed by land, but it is cut off from the sea, on one side, by a reef. One of the largest coral islands is in the Paumota Archipelago, east and north-east of Tahiti. It is Nairsa atoll, or Dean's Island. Its length is fifty miles, and the greatest breadth, including the lagoon, is nineteen miles, so that the whole covers a space on the globe nearly equal to 1,000 square miles. The

inland lake or lagoon is a little sea, but it, like all lagoons, is very shallow in relation to the depth of the ocean a few hundred yards off the outer shore. There are only sixteen square miles of habitable land—dry land—in all this great ring, which is 138 miles round, so narrow is the belt of woodland and trees exists, the coral still living all around, and below the top of the water.

The coral islands are surrounded by very deep sea, and the outer rim or edge of the coral reef, on to which the first rush of the wave is made, is usually part of a precipitous wall of coral growth,

Fig. 1.—A Coral Island or Atoll (Whitsunday Island).

between the rushing wave without and the quiet lagoon within. On the other hand, it has to be mentioned that there are some small coral islands, where a continuous ring of land bounds a depressed inland region, thus indicating the former presence of a lagoon, which is now covered with earth and vegetation.

so that soundings taken a few feet off require much line. A little farther seawards the quantity of line required is much more; and a mile or two off, the profound depths of the ocean exist. Seven miles east of the island of Clermont Tonnere the sounding lead ran out to 6,870 feet without reaching bottom, and within three-quarters of a mile of the northern

Fig. 2.—Section of the Rim of an Atoll. (*After Dana.*)

It appears, then, that there are three stages in the life of a coral island—that of submerged reef, that of a ring of reef and land encircling, more or less, a lagoon, and that of a spot of land without any inner water. In the first part of the history, corals, shells, and certain plants with a calcareous or carbonate of lime covering, and which are called nullipores and corallines, besides the hard parts of foraminifera and of worm tubes, form the reef. In the second, terrestrial vegetation is found; and in the third, a complicated assemblage of plants

part of this island, the lead at another throw, after running out for awhile, brought up an instant at 350 fathoms, and then dropped off again, and descended to 600 fathoms without reaching the bottom. A fathom is 6 feet in length.

At Keeling atoll, at a distance of 2,200 yards from the shore on which the sea was breaking, no bottom was found at 7,200 feet. Thus the seaward slope of the outer part of the reef is not the same in every instance, and in the last example it is steeper than the sides of a volcano. At this island

the sea deepens from the edge of the coral reef very gradually for a distance of between one and two hundred yards to 25 fathoms (150 feet) along a kind of slope, and then the depth increases rapidly, the sides of the rock forming an angle of 45°. The slope seawards from the edge of the reef in most of the islands is great. It is evident that on all sides the circular or triangular coral island rises out of deep water.

Between the outer edge of the reef close to the deep water, and the white-coloured shore, there is a shallow and much-worn rock, like a submerged platform, and it is uncovered here and there at low tide. It may extend a few yards, or more than a hundred, from the shore to the brink of the ocean depths. It is called the shore platform.

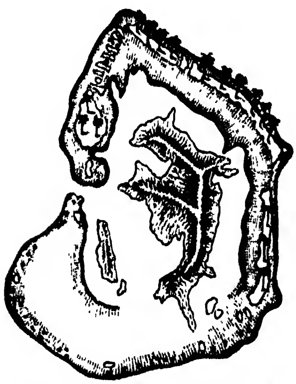


Fig. 3.—Ground Plan of Bolabola Island
(*From Darwin's "Coral Reefs."*)

The lagoon or the lake may have one or several openings into it through the reef and island, and is comparatively shallow. Mr. Darwin, who studied Keeling atoll (Fig. 4), writes that there are spaces in it from three to four fathoms, and smaller spots from eight to ten fathoms, in depth. In the Low Archipelago, the lagoons of the atolls have a depth of from twenty to thirty fathoms; and the depth is slightly more in the Caroline and Marshall islands. But in the Maldive atolls the depth is greater, and reaches from forty-five to fifty fathoms.

The land slopes gradually to the lagoon, but sharply seawards. Although rarely a score of feet above the tide, the land has a little cliff-like face, and a narrow white beach-shore at its foot. Sloping from this beach, which is covered at high tide, is the coral or shore platform already noticed, which may be occasionally uncovered for a little space, and it ends seawards in a number of mounds or in rugged points. These rugged projections are rarely uncovered, and just beyond this point begins the deep water.

The rugged points and mounds consist almost entirely of living coral, and the other living things which produce limestone rock. The surface of the platform, furrowed as it is here and there, and often encumbered with great blocks of dead coral, which have been cast on to it by the waves, from the mounds and points, is for the most part alive with coral polypes, sea anemones, sea urchins, and starfishes. The corals form beautiful parterres of branching, rounded, flat, or leafy masses of colour, every spot being graced by a polype with expanded rays, whose colours may be yellow, orange, grey, green, gold, and white. Every species has its own colours, and there are many of them on every reef. This platform can be examined at low tide, when some of it is above water for awhile, but even then there is the peril of a large wave coming suddenly on to the rock and endangering the student. Near the mounds and jagged points on to which the sea breaks first of all and then rushes over the platform up to the beach, there are many kinds of branching corals, and indeed they mostly consist of them and of great branches and masses which have been broken off and stuck fast. Each branch has branchlets, and they are covered with polype-stars, and these madrepore corals are very light, delicate, and porous, yet equally enduring and strong to resist the rush of the waves. Wrecked often, yet ever growing, these outside corals of the reef are constantly broken off and sent along the platform towards the beach by the inrush of the waves; yet, as a mass, they withstand the surf and the vast billows, and are always striving to increase in bulk, and to grow to just beneath the surface of the water. They require very pure water, which is highly aërated, and they must have a large quantity of food. Less conspicuous, but still forming the solid and enduring part of the reef, are the dome-shaped brain corals and their allies. They are solidly built, and certainly flourish where the water is the least in motion. They are especially the dwellers in the quiet lagoon. Intermediate in shape and solidity between the light and very heavy corals, are many which are found on the platform and amongst the others, and they are rapid yet strong growers. They, and indeed all of the corals of the reef, add to its bulk by obtaining carbonate of lime

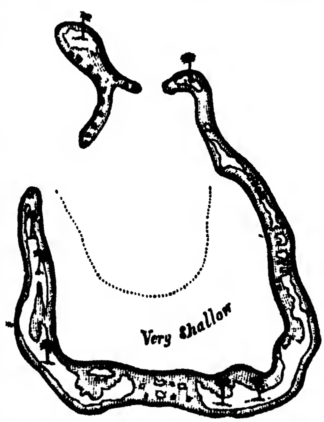


Fig. 4.—Ground Plan of Keeling Atoll.
(*From Darwin's "Coral Reefs."*)

from their food and depositing it within their textures, and they all require water free from mud and filled with air bubbles and air in solution. Their growth has a method in it, which relates to their rapid increase in size and strength with a commensurate lightness. Were these corals to grow by simply adding to the thickness of their structures, or to their height, they would produce vast blocks of solid skeleton of carbonate of lime as hard and as heavy as stone. The increase in bulk would be slow, and, on the other hand, the branching corals would be unwieldy pillars and offshoots; they would be thick, solid, and heavy, and would offer immense resistance to the rush of the waves. The force of the incoming wave and its return, would soon snap off the solid pieces, and the growth of the remaining stem would be very slow. But the corals grow in a definite manner, in which the adaptation of their structures to meet the peculiar requirements of their life and the opposition of the surrounding physical conditions is most evident.

Every polype, as it increases in size, buds, and thus one or more little ones arise from its sides, and soon resemble the parent. These bud in time, and so do their descendants. Now, as soon as the buds attain a very slight height, they become united to the parent, and to one another, by cross pieces of skeleton, which resemble a set of floors, one over the other, with intermediate uprights; in fact, a great cellular structure envelops the growing corals, the spaces being empty. Lightness, strength, and rapidity of growth are thus produced. The weight of the coral is distributed over the largest possible extent of stony surface. All this substance consists of carbonate of lime and a very small proportion of phosphate of lime, some magnesia, and organic matters. The sea anemones do not produce carbonate of lime, but the other inhabitants of the reef do, and, besides those already mentioned, there are several others which are very important in this respect.

On many parts of the reefs, where coral does not grow, the surface of the rock and platform is covered with layers and nodules of a brilliant scarlet or white substance, which, under a low magnifying power, is seen to be made up of a vast number of small cells. It is a vegetable called the Nullipore, and if it be placed in weak acid and water, the carbonate of lime is dissolved and the microscopic peculiarities of a simple plant are shown. Besides these there are vast numbers of other calcareous plants, called corallines, growing in nooks and corners, and great numbers of shells, living and dead, are about the reefs. Some reefs, especially to the north-east of Australia, are partly composed of myriads of flat discs, beautifully cellular under the microscope, and called Orbitolites, belonging to the division of the Protozoa called Foraminifera; and others are composed largely of the hard calcareous tubes of worms besides coral.

There are always large patches on the platforms where there is nothing living, but the rock thus exposed, if the sand and mud be scraped off, is seen to be made up of dead coral; and, according to the size of the reef and the intensity of the prevailing winds, so is the platform covered here and there with huge blocks of dead coral. These, standing above the platform level, have been torn from the outer edge of the reef by the force of the waves, and have been hurled in towards the shore, bruising and often destroying the delicate polypes over which they passed. They collect sooner or later, being much worn in the process, just at the foot of the low land cliff, which is covered only by high tides, and a low tide leaves some inches of water for them to stand in. "On moving these masses," writes Dana, "which generally rest on their projecting angles, and have an open space beneath, the waters at once become alive with fish, shrimps and crabs escaping from their disturbed shelter; and beneath appear various Actiniæ, or living flowers (Sea Anemones), the spiny echini and sluggish bêche-de-mer (holothuriæ), while swarms of shells, having a soldier-crab for their tenant, walk off with unusual life and stateliness. Moreover, delicate corallines, Ascidiæ, and sponges, tint with lovely shades of red, green, and pink the under surface of the block of coral which had formed the roof of the little grotto." Some of these masses of coral are so large that they become fixed to the platform before the waves have power to roll them up to the beach. They may measure six or more feet in height; and their weight and a peculiar process of consolidation, which will be noticed further on, tend to unite them with the surface of the coral on which they rest. Some get worn by the waves and the air, and assume the shape of mushrooms, or great balls fixed on a stalk. So vast are these blocks on some reefs, that they measure a thousand cubic feet and more. The result of their wearing by the rush of the sea, and of the crumbling effect of the sun and air, is to produce considerable quantities of pieces which get rolled into pebbles, and much white sand is produced. The pebbles and sand, of course, consist of carbonate of lime, the material of the coral. Some of the sand is washed away into deep water, but more

of it is carried gradually with the pebbles, and cast high and dry on the beach. These great blocks and the pebbles and sand, produced by the wreckage of the reef, and carried inwards, are of great importance, for they form the foundations of the land of the coral island, which is raised, as it were, on and at the expense of the reef. Year after year the winds and waves carry blocks beyond the reach of the sea, and they become piled up one over the other, the heap sloping towards the lagoon, and having more or less of a cliff of a few feet seawards. The cliff is produced by the everlasting wear of the blocks, and their seaward face is worn into sand, mud, and pebbles, which collect on the beach at its foot. This beach is very remarkable in its construction, and is of great interest to geologists, for it affords an explanation of the manner in which many ancient deposits accumulated. It is usually remarkably white in colour, and this tint contrasts singularly with the green of the foliage on the top of the low cliff close by. It consists partly of waifs and strays, such as crab-shells, fish-bones, and sea shells, all much worn and rolled, and mainly of worn pieces and grains of sand, the result of the rolling about of coral. This sandy beach is exposed to the tide, and when that is low, to the action of a hot sun, and it thus becomes wet, and dry and hot, undergoing alterations chemically and physically. The water of the sea dissolves some carbonate of lime, and this is deposited and hardens among the grains of sand and little fragments, uniting them together. Thus the cellular parts of the coral pebbles get filled up with all sorts of minute calcareous particles, the whole being cemented by the added carbonate of lime. After a while, the deeper layers of the beach sand unite and form a solid limestone, and the pebbles collect together, and are united into a kind of "plum-pudding" stone, or conglomerate. But the most interesting change is that which produces, in the beach sand, the appearance of such rocks as are called Oolites by geologists. A small particle of coral, or a foraminifer, gets covered with sea-water, which deposits a film of carbonate of lime around it. The little mass rolls about, collects minute grains upon it, and is again coated, and the process being repeated several times, a little globular mass results, so that a number of them resembles the roe of a fish in shape. These egg-like stones, or Oolites, become agglutinated, and form limestones. In some coral islands the sand of the beach is so plentiful, and the winds are so strong, that it is carried on to the face of the cliff and on to the top of it, so that the vegetation and sand struggle for place. The sand is, of course, made up of carbonate of lime, and as the spray of the sea reaches it and waves sometimes dash on to it, a deposit of cementing substance occurs, and finally a limestone is produced which adds, in the long run, to the bulk and height of the land.

Beyond the submerged platform with its living corals, and farther in than the white beach of coral sand and its blocks, rises the low cliff which bounds seawards the narrow and low land of the coral island. This land, in the first instance, was a confused heap of blocks of dead coral, which years of wave-toil had cast up high and dry above the beach; and this confused arrangement of large and small masses of rock can sometimes be detected even when vegetation has grown on the top of all. Angular pieces of coral, cemented together by carbonate of lime, and piled up in the greatest confusion, and blackened by exposure, and by encrusting lichens, form the bulk of the foundation of the soil, which, in after years, collects slowly enough. Its formation is assisted by the blowing in, amongst the blocks, of the coral sand, and by the consolidation of the whole by the effects of rain-water and sea-spray; so that solid rock fills up the cracks and crannies, and a strong, hard formation is produced.

The earliest vegetation occurs on the top of the new land, and Dana states that after the coral sand has found lodgment amongst the blocks, some seeds come to the land and take root, and Vines, Purslane, and a few shrubs begin to grow, relieving the scene, by their green leaves, of much of its desolate aspect. Still the land is low, and furious gales and stormy seas now and then cast blocks on to it, so that even when trees have grown, and a considerable amount of soil has been produced, many large blocks of coral may be seen black amongst the green foliage. The soil has but slight depth, although the land may be covered with vegetation, and it is in fact mainly formed by coral sand, there being but little mould, which is the result of the decomposition of plants and of the leavings of birds.

On the side of this new land, remote from the encircling sea, is a slope which leads to the lagoon, and it ends in a muddy or sandy beach, with coral growing, here and there, below the tide mark. The sea in the lagoon is often rough, although the land and reef act as a breakwater; and when these inland lakes are very large, the sea breaks with force on these shores, and forms a platform which is on a level with that on the seaward side of the island. The lagoon platform is usually more sub-

merged than the other, and is covered with massive growing corals, and it drops down suddenly into the depths of the inland lake, amidst a forest of corals, down to a bottom of sand. On some small islands the lagoon shore is a plastic mud, the result of the wear and attrition of coral sand, and of the digested matters of the myriads of living things which prey upon the coral. It is this fine mud which chokes up the lagoons, in some instances, and forms the subsoil of the low inner district already noticed to exist in some coral islands.

A perfect coral island, or a completed atoll, is a little paradise in the midst of the turbulent ocean, and its still lagoon, green underwood, and groves of tall trees contrast with the wild waste of surf and wave around. It is not every Coral island that has a shady woodland, but some have cocoa-nut trees, screw pines with their sword-shaped leaves, great Pisonias rising up to a height of 40 feet, and having a handsome foliage and large and beautiful flowers, and Purslanes and Borages. A fleshy sea-plant grows close to the shore, and the flora (or collection of plants), as a whole, is small in number, but striking. Most of the seeds have been sea-borne, or carried by birds accidentally; but man, savage and civilised, has introduced the Cocoanut, the Banana, and the Bread-fruit. A few ferns, Heliotropes, and Euphorbias add to the beauty of the original vegetation of the coral island, which usually does not contain many kinds of plants. Birds abound, and here and there a reptile, but there are no native quadrupeds.

As the coral island is made up of the wreckage of the growing coral of the reef, which is, as it were, its foundation, it can only exist in those parts of the world were coral can grow easily and luxuriantly. It has been stated that the islands stand in very deep water, and that whilst the living coral struggles to live just under the wave, so the land is not more than from 12 to 20 feet out of water. Now, Mr. Darwin and all subsequent investigators have shown that the reef-building corals cannot flourish, and in most instances cannot live, at a greater depth than 20 fathoms. They require a certain temperature of sea-water, and although they live in water at the surface of the ocean, which has a temperature of from 68° to nearly 80° Fahr., the slight diminution in temperature at a depth of 120 feet, with a diminishing quantity of food, prevents their development there. Moreover, the corals die if much sediment exists in the water. A deep sea, remote from large land surfaces, where the sun's heat is great, or where there are warm currents at the surface, is the home of the coral island, and it forms an irregular belt on both sides of the equator in the Pacific and Indian Oceans. About 20° north and south of the equator, will include the coral islands of those oceans. In the Atlantic the Bermudas are more than 30° north of the equator, but the warm waters of the Gulf Stream enliven their coral growth. It is evident that as the water is very cold on the floor of the ocean, the coral reef cannot originate there and grow upwards for 12,000 and more feet, to the surface. Growing not at a greater depth than 120 feet, it might be supposed that the coral commenced its life on the top of a submerged mountain, and grew up in its curious ring-shape to the surface. But this simple explanation will not satisfy other considerations. Thus it has happened during the great movements of the earth's crust that coral islands have been bodily raised, reef and all, out of the sea, to form high land, and the geologist has found much more than 120 feet of coral substance all turned into limestone rock. It is clear that, if this coral originated on a submerged mountain and grew upwards 120 feet, the mountain must have sunken down subsequently, and that a corresponding upward growth of coral has taken place. The thickness of the coral limestone could be explained in that manner. That there is truth in this will be noticed if the other considerations be entertained.

Thus, there are many islands in the Pacific and Indian Oceans where a mountain or a range of hills, dales, and plains stands up in very deep water all covered with verdure. They are made up of many kinds of rock, earth, and stone, and not of coral. But where the sea washes the shore, there is a low shelving beach just under water, which is made up of living and dead coral. Deep water exists where this platform ends seawards, and where the rapidly-growing madrepores come close up to the surface. This reef of coral encircles the islands except where streams and rivers enter the sea, and living coral is got by dredging at a depth of 120 feet. Such a reef is called a fringing reef.

There are other islands in which the central mountain is not so tall, and there is only a little coral growth attached to them. But all around, at a distance of four or five hundred yards to some miles, is a belt of calm water, and beyond those distances the sea is seen to break on a great natural breakwater or coral reef. This coral reef often has land on it, the product of the same causes which produce the coral island. It stands in deep water, and within

its circle are the central mountain and the belt of shallow water representing the lagoon of the atoll. This is called a barrier reef, and although living coral exists on its seaward face at a depth of 120 feet only, dead coral is found at a greater depth.

In fact, the examination of the fringing reef, and then of the barrier reef, having the peculiar construction of the atoll and coral island in view, leads to the belief that they are all parts of one great natural event.

No mountain can be fashioned under the sea, for the peaks and the abrupt slopes are the result of the denuding action of cold, heat, the sun, the air, and moisture. The depths of the sea are still, and deposition goes on there. The long lines of partly-submerged mountains of the great ocean* once formed the boundaries of continents, and their consideration involves the key to the comprehension of the history of the coral island. Subsidence on a grand scale has taken place, and the sea has invaded the land, and the coral island situated on a submerged mountain top is its memorial monument.

Taking a partly submerged mountain as the commencement of the story, a fringe of coral grew around its slopes from 120 feet up to the surface of the sea. Slow subsidence progressed, and as the supporting land sank, the coral grew straightly upwards. After a while the slope of the mountain, between the fringing reef and the now much sunken hill, became occupied by water, and the original fringing reef became a barrier. Still sinking, the mountain-top disappeared, and still growing upward, the coral ever came to the surface as an encircling reef, a lagoon finally replacing the belt of water and the mountain top. Then the atoll was completed.

If this process of subsidence persists, the reef ever growing upwards, and the coral dying as it descends below 120 feet, the coral mass will become thicker and thicker. But if, after a while, subsidence ceases, the wreckage of the coral will be cast up by the waves and the foundations of the coral island laid. Then vegetation commences, birds visit the new land, and finally man occupies it.

THE PHILOSOPHY OF A GLANCE.

By William Ackroyd, Fellow of the Institute of Chemistry, etc.

ONCE on a time a young student was busy at work in the Royal Society's Rooms at Burlington House, learning, by aid of the volumes which surrounded him, what had been done in his particular corner of science. For hours he was poring over the books and making notes, when suddenly, on lifting up his eyes, he found the glance of Newton fixed full upon him! Well, there was nothing in this, it was only the glance of a picture; but he perceived later on that, no matter what part of the room he was in, the seer's eyes still looked down approvingly on him. Would the great *savant* presently step out bodily from the frame, and invest this young aspirant with his mantle? The student in question never thought it; he more sensibly concluded that here there was a curious phenomenon, which was quite explicable, and the explanation he found in one of the works of the late Sir David Brewster.† He thus speaks of the phenomenon:—"This curious fact has often been skilfully employed by the novelist, in alarming the fears or exciting the courage of his hero. On returning to the hall of his ancestors, his attention is powerfully fixed on the grim portraits which surround him. The parts which they have respectively performed in the family history rise to his mind; his own actions, whether good or evil, are called up in contrast, and as the preserver or the destroyer of his line, he stands as it were in judgment before them. His imagination, thus excited by conflicting feelings, transfers a sort of vitality to the canvas, and if the personages do not 'start from their frames,' they will at least bend upon him their frowns or their approbation. It is in vain that he tries to evade their scrutiny. Wherever he goes, their eyes eagerly pursue him; they will seem even to look at him over their shoulders, and he will find it impossible to shun their gaze but by quitting the apartment." We cannot do better than give Brewster's explanation:—"Let us suppose a portrait with its face and its eyes directed straight in front so as to look at the spectator. Let a straight line be drawn through the tip of the nose, and half-way between the eyes, which we shall call the middle line. On each side of this middle line there will be the same breadth of head, of cheek, and of neck, and each iris will be

* "Science for All," Vol. II., p. 320.

† "Letters on Natural Magic," pp. 117-8.

in the middle of the whole of the eye. If we now go to one side, the apparent horizontal breadth of every part of the head and face will be diminished, but the parts on each side of the middle line will be diminished equally; and at any position, however oblique, there will be the same breadth of face on

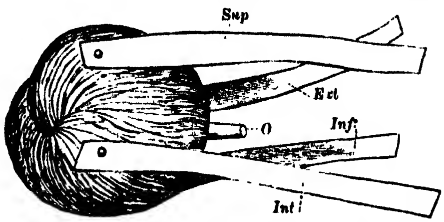


Fig. 1.—Diagram showing the Position of the Straight Muscles of the Eye: *Sup.*, Superior Rectus; *Inf.*, Inferior Rectus; *Int.*, Internal Rectus; *Ext.*, External Rectus; *O*, Optic Nerve.

each side of the middle line, and the iris will be in the centre of the whole of the eyeball, so that the portrait preserves all the characters of a figure looking at the spectator, and must necessarily do so wherever he stands."

So much for the glance of a man on canvas. Now, in the real man, or any living object, one can generally tell in what direction the glance is turned by the appearance of "the whites." In a person looking full at anything, the pupil occupies the centre of the eye, and if he still look at the same object with the face turned a little to one side, the pupil no longer appears in the centre, more white being seen on one side of it than on the other. It is a remarkable fact, however, that in the direct glance considerable misconception may arise. A guilty student often thinks the eyes of his professor are fixed full upon him when in reality they are turned towards some person two or three places to the right or left. This peculiarity, as we have just seen, is strikingly observed in pictures.

A moment's thought is not necessary to see how inconvenient it would be for one to lack the means of turning the eyes about; and as we learn more particulars of these movements, we shall find that mobility of the eyes is absolutely necessary for the purposes of distinct vision. Were the eyes fixed, as in a waxen figure, we should have an exception to Nature's general law—that every organ is admirably fitted for the end it is designed to subserve—and accordingly we find that an eyeball is worked by many muscles. It has a muscle to turn it heavenwards, one to turn it earthwards, another to turn it to the right, and one to turn it to the left, besides two more muscles of somewhat complicated action—six outside muscles, in all, for one eye, and twelve to work the pair of eyes. By outside we here mean, exterior to the eyeball. In the absence of a dissected eye, an idea of the positions of these muscles may be obtained from a rough model (Fig. 1). Let a small ball of worsted represent the eyeball. A plug of paper *o* inserted a little to one side of the axial orifice will represent the optic nerve, and four strips of paper attached by pins, one at the top, another directly under it, and two at opposite points midway between these, will represent what are called the straight or recti muscles. It will be seen, therefore, that these muscles are attached to a zone of the eye which divides the front from the back part, and at their other ends they are fixed very near where the optic nerve leaves the socket on its way to the brain. When any one of these muscles contracts, it has the same effect on the eyeball as pulling one of the paper strips has on our model. The top muscle is called the superior rectus; the bottom muscle, the inferior rectus; the muscle on the nasal side of the eyeball is the internal rectus, and the remaining one the external rectus. When one looks upwards, the superior recti muscles are used; in glancing downwards, the inferior recti muscles are brought into play; and upon turning the eyes to look towards the right hand, the internal rectus of the left eye, and the external rectus of the right eye are both used together. In that rolling of the eyes so much affected by "negro" minstrels, we have, of course, a combined action of these straight muscles.

The axis of a body is a line with respect to which its parts are symmetrical, so that the axis of the eye is an imaginary line passing through the centres of the cornea, lens, and eyeball. This line is generally called the *optic axis*. The action of these straight muscles is therefore to alter the direction of the axes of the eyes as may be required at any moment for the convenience of vision. When we make these axes converge upon a near object placed in front of us, we may, by bringing the body nearer and nearer, get a degree of convergence that becomes a decided squint. The reader will see, therefore, that in squinting we make an undue use of the internal straight muscles.

We have said that there are six outside muscles to each eye; four we have described, the remaining two are called oblique muscles, and they are employed to turn the eye on its axis, to make it rotate, consequently they are fixed in a different way from the recti muscles. Think for a moment how a top is turned: we have string wound round it which we pull; so, in like manner, one of these oblique

muscles is partly wound round the eyeball, and the other is fixed in a more complicated manner; suffice it to say that their general action is to rotate the eyes on their axes. This takes place unconsciously to ourselves whenever we incline the head to one side or the other, and we have in these muscles a natural device for preserving that constancy of position, which we see effected artificially in the bearings of a ship's compass.

We are now roughly acquainted with the external mechanism of the eye, and we say "roughly" purposely, for we have not stayed to inquire into the nature of these straight muscles, whence they receive their commands to contract, and how the message is conveyed to them; and we must pass on to consider a curious difficulty which presents itself in further studying the phenomena of vision. How comes it that we see an object a mile away on a clear day as well, so far as its general form is concerned, as we can when it is only a few yards off? Because a very simple experiment makes it quite apparent that if the inside parts of the eye were rigidly fixed, the image in one case would be much more indistinct than in the other. Let us see this experimentally. Take a plain caraffe (*f*, Fig. 2, I.), filled with water, and place a candle *c* on one side of it, say a foot away. Now adjust the distance of a paper screen *s* held by a book *b* on the other side, so that a perfect image *i* of the inverted candle is seen on it. Try now the effect of altering the distance of the candle from the flask, taking it say several feet away (Fig. 2, II.). The image on the screen is no longer distinct, and to make it so we have to move the sheet of paper towards the

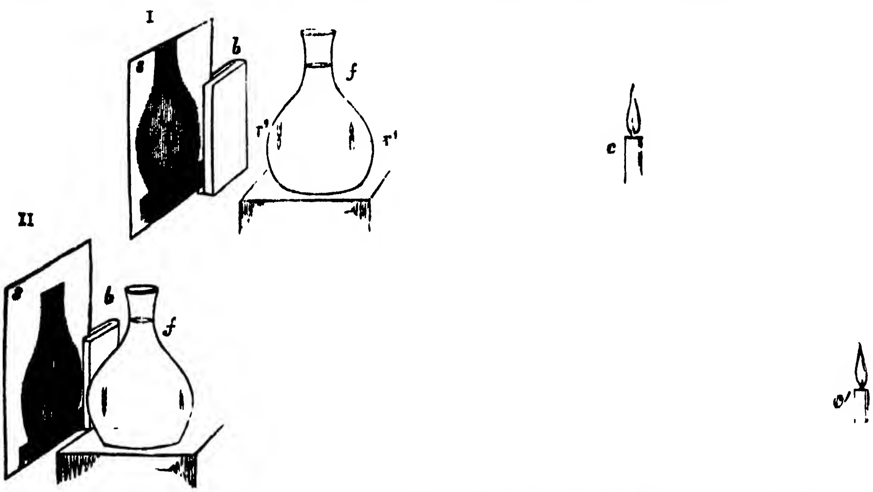


Fig. 2.—Illustrating how the Position of the Screen (*s*) has to be altered with different Positions of the Candle (*c*), to keep a perfect Image on the Screen.

flask to a nearer position. In the eye the crystalline lens forms the image, and the retina answers the part of a screen. Is the retina a movable screen? When I transfer my gaze from the homestead a hundred yards away to one a couple of miles off, do I unconsciously shift the position of my retina towards the lens? The images in each case are perfectly distinct, but it seems exceedingly unlikely that this distinctness is obtained by a shifting of the retina, for we know that the eyeball is closely stuffed with a jelly-like substance, and is not unlike the golden ball filled with water, and closed at every point, that was used by the Florentine wise men, to ascertain whether water was compressible; and just as these *savans* found, on compressing their ball, that water oozed out, so it is not improbable that we should find here that the required displacement of the back of the eye would cause its contents to exude. Movement of the retina is therefore out of the question in seeking for an explanation of this phenomenon; equally absurd would it be to suppose that the lens is bodily shifted. The solution of the problem may be ascertained in a very simple manner. On the front of our flask will be seen an upright image of the candle r^1, and an inverted image appears at the back r^2; similarly two images are reflected by the crystalline lens, one upright from the first surface, and a second inverted, which is reflected internally from its back surface. Now if a taper be held sufficiently near to the eye these two images may be seen by a person properly placed, and likewise a third upright image which is reflected from the front of the cornea. The middle image alters its position with respect to the other two every time the person being experimented upon transfers his attention from a near to a distant object, or from a distant to a near object. We can interpret this experiment only in one way: it tells us that the lens alters its form by making its front surface more or less convex, and by this means a perfect image is

produced on the retina, whether the thing gazed at be far off or near. This change in the crystalline lens seems to be effected by means of a peculiar muscle, ring-shaped, and concentric with the iris. The outer edge of this ciliary muscle, as it is called, is attached to the same portion of the cornea as the inner margin of the iris (Fig. 1, p. 111). Whenever we look at a very near object, we contract this muscle, which so acts upon the attachments of the lens as to allow it to become more convex on its front surface; instantly the glance is transferred to a distant object, the ciliary muscle ceases to contract, and the lens is now pulled by its attachments into a flatter form. This device enables us, without being aware of it, to bring pictures of external bodies, whether far off or near, perfectly on to the retina without the retinal membrane having to alter its position. That the eyes have to be focussed for objects at different distances is very evident in the following simple experiment. Stick two stocking needles perpendicularly into a piece of wood, and about nine inches from each other. Now regard the first one at a distance of another nine inches with the eye nearly in the same straight line as the two. By no means can both these needles be seen distinctly together. If the near one be seen distinctly, the far one appears double; and, *vice versâ*, if the far one be gazed at particularly, a double image of the near one is observed. The needles seen in these double images appear blurred and indistinct. Moreover, in repeatedly bringing them into view a sense of effort is experienced.

The focussing of the eye has doubtless something to do with the perception of distance; for a certain state of the ciliary muscle and lens must always be associated with the idea of distance, whilst a certain other state will never fail to be an index of nearness. And many other facts co-operate with these to give us a more or less perfect perception of distance, a very important one being the size of the image on the retina; for just as, in the course of our experiments with the water-flask, we shall have noticed that the size of the image on the screen becomes less and less the farther we take the candle away (Fig. 2, I. and II.), so, in like manner, the greater the distance becomes of an object from the observer, the less is the image projected on to the retina. Moreover, if the object remain the same, the greater the area of retina which it affects, the nearer we judge it to be to us; and conversely, the less the area of retinal nerve-matter it covers, the farther off we think it is. Another important element in the perception of distance is the use of the outside eye-muscles; for in looking at near objects, as the reader already knows, we contract the internal recti muscles, and this action we come to associate with an idea of short distance, and the less the amount of action the farther off we think things are, so that when the eyes are directed to a far-off object the very fact of our not having to use the recti muscles much in converging the axes of the eyes, gives us the impression that the thing we are staring at is a long distance away. An act of the mind alone, however, calling upon past experience, may give one the idea of nearness or distance. All parts of A (Fig. 3) are evidently in the same plane, but the inner square appears farther off or nearer than the outside or marginal square, just as I have a mind to think it. If I think the inner square farther away, I unconsciously call up its resemblance to a room

A B

Fig. 3.—Illustrating the Action of the Mind in Judging of Appearance.

with a square wall at the end, and the floor, ceiling and two sides sloping towards it; on the other hand, if I think the inner square is nearer to me, it is because I am thinking I am looking down on a pyramid with its top cut off. The source of the effect in each case are the converging lines which join the corners of the two squares. No effort of mind can remove the impression that in B (Fig. 3), the inner square is in the same plane as the outside square. Yet the squares in B are of precisely the same size as the squares in A, only instead of converging lines joining the corners we have lines parallel to the sides, which bring up the idea of a wall with a square hole in it; and our past experience tells us that the wall and the hole are invariably in the same plane. Such ideas are a source of annoyance sometimes to geometricians, for in the complex figures they are studying, angles which ought to appear receding seem to be projecting; and, on the contrary, angles that ought to be projecting will persist in appearing as though they were

receding. In Fig. 4 the angle A will appear either nearer than B or farther away than it, just as one regards the figure as leaning forward and a little to the right, or as leaning backwards and a little to the right. The reader may have a difficulty at first in realising this; let him therefore fix his eye on the point he wishes to seem nearest, whether A or B, and regard this as a projecting solid angle; this done, the other parts will appear in unison behind it. Every part of the figure being in the same plane, it is evident that no muscles of the eye are concerned in this action; it is a mental operation pure and simple.

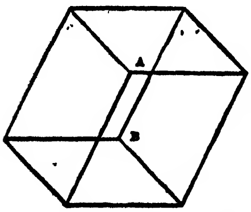


Fig. 4.—The Illusive Appearance of a Geometrical Figure.

Putting these illusions on one side, our ideas of distance are founded largely on variation in size of the retinal image, and on muscular sensation. The artist, when sketching a scene wherein there are many objects of the same size at various distances, puts them of different sizes in his sketch, and in order that distance may be accurately expressed, he ascertains the relative amount of space they must cover, by employing the simple device of measuring their relative lengths and breadths by means of his pencil extended at arm's length. If he be using the brush alone he fails not, according to well-known rules of his art, to give impressions of nearness and distance by means of his colours, putting a fair proportion of warm red in the foreground, and of cold misty blue in the back. From a consideration of such artistic practices, Prof. S. P. Thompson has quite recently come to the conclusion, on physical grounds, that the chromatic aberration of the eye accounts for the universal opinion of painters as to the "retiring" character of blue, and the "advancing" character of red tints. Let us cursorily examine these grounds of belief. As a result of the chromatic aberration of the eye we know all rays are not brought to a focus in the same plane. If the rays *r r'* (Fig. 5) be blue, they are brought to a focus at *i*; if they be red they are brought to a focus at *i'*. Suppose then we were to look at a point of light, such as a silvered button in the sunlight, through a purple solution of permanganate of potash, this button would appear either red or bluish-violet, according as the eye was adjusted for the image *i'*, or *i*. It is, moreover, evident that there would be a difference in the amount of effort necessary to see the two images in Fig. 5 similar to that experienced in accommodating the eye to the two positions of the candle in Fig. 2. And just as in Fig. 2 the adjustment of the eye for *i* II. leads us to suppose that the candle is farther away than a similar adjustment for *i'* I. does, so in Fig. 5, as a matter of past experience, we should think the light source producing *i* farther off than that originating *i'*. Thus it arises that in the chromatic aberration of the eye, what many have regarded as a serious fault, becomes an important element in the perception of distance; so much so that Thompson observes, "Reflecting how useful is the purpose subserved thus by the non-achromatism of the eye, I consider it probable that if the eye were so constructed as to be originally achromatic, having usually blue distances, and red-brown foregrounds to look at, it would, by an inevitable process of natural selection, develop into a non-achromatic instrument." *

And now as to size. An object with which we are perfectly familiar, and which we have felt and examined minutely, has an image which covers a certain area of the retina. All objects at the same distance, whose images cover a larger extent of retina, we regard as bigger, and all with images less we regard as less than the familiar thing we have compared them with. The image of a cow, for example, covers a larger area of the retina than a dog the same distance away; the cow, we therefore conclude, is the larger of the two. Our ideas of size are obtained by such comparisons, and in the representation of little known or rarely seen objects, we have to introduce familiar ones with which they may be compared. No idea of the size of St. Peter's, at Rome, could be formed from a picture of it, were there not in the foreground a few men and animals from which to get our unit of measurement; and similarly in any sketch of a

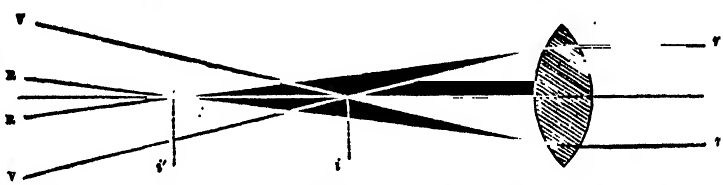


Fig. 5.—The Chromatic Aberration of the Eye in relation to the Perception of Distance.

* *Proceedings of the Physical Society of London*, Vol. II., p. 170.

gigantic animal or tree, this device must be adopted to produce a popular idea of its size: thus by the side of the colossal skeleton of the Siberian mammoth we place a Russian "moujik" gazing in mute wonder, or by the side of the Victoria water-lily at Kew we put the figure of a botanist looking at it with a more intelligent interest.

In order that we may leave as little as possible unexplained, we may now turn to consider why in the needle experiment we saw two needles where there was only one when the eye was not adjusted for it; and in seeking for an explanation we are brought to consider a peculiarity which pervades perhaps all the parts of the eye, *sympathy of action.* If the iris of one eye contract, so will the other; if one expand, so will its fellow, and this as it were purely in sympathy, as will be seen from the following simple experiments:—If, in the pin-head experiment, described on a previous page (p. 112), much light is let fall into the eye which is not regarding the pin without the quantity falling into the observing eye being altered, it will be seen that although there is no alteration of the amount of light entering the observing eye, its iris expands in sympathy with that of the other eye into which there has been a sudden influx of light. The converse experiment is described by Lord Bacon, and is this: while light is entering both eyes, the iris of one is regarded in a mirror, and the other is closed. The observed iris contracts in sympathy with the one which has been covered up by the eyelid.

The muscles of the eye are also sympathetic in their action, the muscles of one eye working in unison with those of the other, and the parts of the two retinæ are sympathetic. In support of the latter fact, we may here give the particulars of an experiment Newton tried—a dangerous one, which we advise the reader not to repeat. This philosopher gazed at the image of the sun in a looking-glass for a short time, and found afterwards that he could make its image re-appear as often as he liked by going into the dark, and *he could see the image with the left eye alone almost as easily as with the right, on which it was originally stamped.* This peculiarity increased to such an alarming extent, that before long he could look upon no bright object without seeing in it the image of the sun. He recovered the proper use of his eyes by keeping in a dark room for several days, and forbearing from either reading or writing. The italicised words in the foregoing account give the curious part of this experiment, and support the idea that there are sympathetic areas of the two retinæ. Two such areas are the central spots upon which the images of objects are caused to fall when we direct our eyes and our attention upon them. For example, I am inspecting the ink-stand a few yards away; there are two images of it formed on my retinæ, and both on corresponding parts of these retinæ, that is, on the central spots, and falling on these sympathetic areas they produce the impression of one ink-stand. It has been a transmitted experience, that whenever similar images have fallen upon these areas of the retinæ, an idea of singleness has been produced, for by handling the thing only one has been found, and to-day we, as the inheritors of this experience, know at once there is but one ink-stand, and have only an idea of one, although a pair of images are formed on our retinæ. If, however, these images were to fall on areas not accustomed to work together, two inkstands would be seen; hence it arises that when the muscles which regulate the movements of the eyes are weak and unable to properly fulfil their duties, images of external objects are thrown on to unsympathetic areas of the retinæ, giving rise to *double sight* or *diplopia.* In the healthy eye this may be effected by squeezing one eyeball slightly, and thus, by diverting the rays which are entering the eye, an image is formed on an area of retina not corresponding to that of the other eye upon which an image rests; two objects are thus seen where there is only one. Let us now inquire what parts of two retinæ belonging to a pair of eyes work together or are sympathetic. The consideration of three simple cases will tell us what we want to know. First, the eyes are directed towards a candle a few yards away; here the images fall on the central parts of the retinæ known as the "yellow spots"; second, the eyes are still fixed on the same place, but the candle is removed a little to the right; the images no longer fall on the yellow spots, but a little to the left of each; third, the eyes being still fixed on the same place as at first, the candle is now moved to the left as much as it was before to the right; the images now fall on the right of the yellow spots. In each case there is sympathetic action of the retinal areas at work, because only one light is seen. Hence it would appear from this experiment that the exact centres of the two retinæ work together; that certain regions to the left of these centres work together, and certain regions to the right. Suppose now we could see the backs of the eyes

with the images formed on them in this experiment, as though the eyes were cut in halves, and the front parts removed, it would be not unlike looking into a couple of acorn cups with pictures of an inverted candle painted in their hollows, and what we should see may be represented by I., II., III., in Fig. 6, where it will be seen that in the first case the images occupy the exact centres, and in the second and third positions they stand

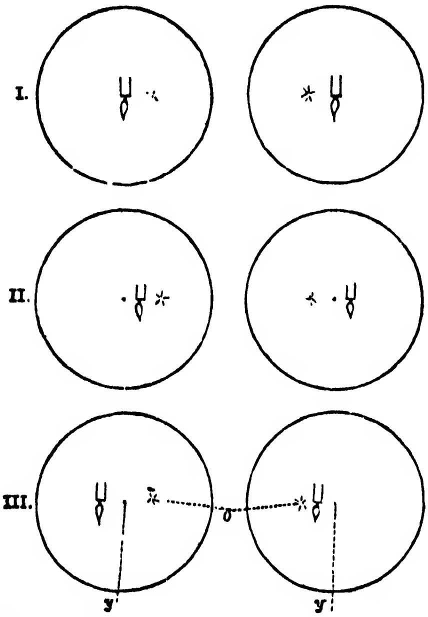


Fig. 6.—Images Formed on the Backs of a Pair of Eyes.
(o) Entrance of Optic Nerve; (y) Yellow Spot, or *Macula lutea*.

to one side of them. The blind spots are unsympathetic areas, and consequently in normal vision the image of an object never falls on the two blind spots together, for if one blind spot be occupied by an image, the corresponding image in the other eye falls on a sensitive area of retina, and thus no inconvenience arises. If the images of a single object be made to fall on the internal or nose side of each yellow spot; or one image on a central spot, while the other occupies in the other eye a position to one side of it, in all such cases a single object appears double. It will now be evident why two needles were seen instead of one in the needle experiment. When the eyes were turned towards the far needle and adjusted for distinctly seeing it, blurred images of the near one were formed on the external side of each yellow spot—unsympathetic areas. On the other hand, when the sight was adjusted for the near needle, images of the far one fell on the internal and unsympathetic sides of the yellow spots. An amusing form of the latter experiment may be thus tried. Look at a finger held pointing upwards a couple of feet away with a candle in the line of vision several feet off; while the eyes are adjusted for the finger there appear to be two candles, because the images fall on unsympathetic retinal areas.

We have seen that when the eye is adjusted for near objects the front surface of the lens bulges out more than ordinarily, and that if this fulness of the lens be retained, distant objects will seem blurred and doubled, because their images cannot fall completely on the retinæ nor on sympathetic areas of them. One of these effects would be produced if, all other things being right, the surface of the cornea bulged out more than enough, or the substances of the eye bent the rays too much. For with such a *myopic* or "short-sighted" eye the image of an object some distance off is formed in front of the retina instead of upon it, and seems blurred and indistinct. This is a state of things analogous to that represented in Fig. 2 I., where, to get a distinct image on the screen, a candle a long way off has to be brought up to within a foot off the flask. Similarly, people with short sight have to bring objects near, in order to see them plainly, or, in other words, to plant their images fairly on the retinæ. The same end may be attained by the use of a double concave glass of such a curvature as to neutralise the bad effects of the too convex form of the cornea. On the other hand the cornea may be too flat, may not have curvature enough, and the materials of the eye may not have sufficient light-bending power. Under such circumstances the images of external objects would be formed at a place beyond the retina, if the back parts of the eye were transparent; and to get distinct vision the images must be brought forward and projected on to the retina. Near objects cannot be plainly seen until this is done either by using a convex lens, or placing the object a long way off. Such "long-sightedness" is a condition common to aged persons, whence the name *presbyopic*, by which it is known.

The image being fairly planted on the retina, that series of actions takes place which we have tried to describe in the paper on "The Eye and Its Use," p. 110. Wondrously well defined pictures are formed, faithfully representing external nature in form, tint, and shade, and from these we get our ideas of that which is without us. The light producing these images is not very strong, having been reflected once, twice, or more times since

leaving the sun, and at each reflection it has been weakened. This is a matter of some importance, for, when light proceeds directly from a luminous source into the eye, if it be very strong like the sun's light, the visual organ may be injured, as we have seen, and in any case the peculiar phenomenon termed *irradiation* may be observed, a phenomenon in which the impression produced on the retina extends beyond the outline of the image. The biologist tells us that the retina is but modified skin, skin which has been so altered as to be sensible to the impact of ether waves, just as the skin of one's hand is sensible to the rap of a hard body. Now it has elsewhere been shown* that there is a limit to the discriminating power of the skin, that two compass points, when sufficiently near to each other, will be discerned only as one if they be brought to bear on the skin; in like manner the retina behaves in this phenomenon of irradiation.

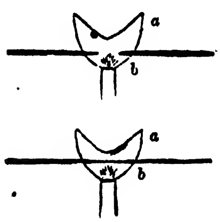


Fig. 7.—Irradiation.

Take a piece of black thread and regard it steadily against the glaring gas-light some yards away. (Fig. 7). The continuity of the thread seems broken. Why? On the retina there will be projected images of the two halves of the flame *a* and *b*. These images represent areas of the retina strongly agitated, and we see here that two distinct areas of impression merge into each other and appear as one. With a thicker thread I should get a distinct separation of the half images, and obtain on a small scale the phenomenon described on p. 168, Vol. I., where the full sun apparently indents a telegraph pole which stands full in the way of the observer looking at it.

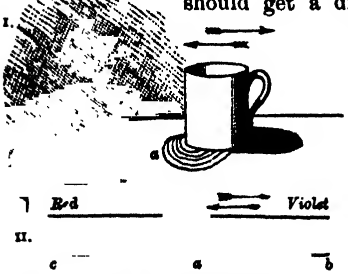


Fig. 8.—Irradiation Experiments.

There is another set of irradiation phenomena which is of great interest, in which it appears that the retina under certain circumstances cannot well discern between minute differences in quantity of light. One or two illustrations of this have come under my notice. This is a very homely one: take a white porcelain vessel (Fig. 8) and lay it on a white sheet of paper or a white table-cloth, with the gas lit some distance over and on one side of it as in Fig. 8, I. *b*. A number of rings, dark and bright alternating, will be observed on the opposite side of the pot to that on which its shadow lies. It is foreign to our present purpose to inquire into what these dark and bright lines are due to; what we have to note is that if these lines differ very little from the white cover in intensity they vanish, or rather, one cannot perceive them after gazing at them for a few seconds. If, however, the pot be moved to and fro in the direction of the arrows, the dark and bright lines are at once visible. Another experiment illustrating the same fact is this. When examining a very faint absorption band it seems to be soon effaced in the light of the remaining spectrum; that is, if in looking (Fig. 8, II.) at the spectrum *c b*, we steadily gaze at the very faint band *a* for the purpose of fixing its position, it very soon disappears, but if we slide the telescope rapidly first to the right and then to the left for several times, the band is plainly seen during the movement. This displacement of the telescope amounts to the spectrum being moved rapidly backwards and forwards in the direction of the arrows. From these experiments we may conclude, then, *that a band either more or less luminous than the ground on which it is cast when continuously presented to the same point of the retina becomes invisible, but by continually shifting the place of the image of the object on the retina the band may be rendered permanently visible.* Herein lies the explanation of the fact that we see the *Purkinje's figures*, described on p. 116, only when the candle is kept moving up and down. The sensitive portion of the retina is the layer of rods and cones. But the rods and cones are behind these ramifying blood-vessels. Therefore faint shadows of these vessels fall upon the back and sensitive portion of the retina, and can be discerned only when the candle is kept moving. If, whilst looking at the Purkinje's figures, one ceases to move the candle for a moment, the figures disappear. The above is a simplification of the proposition enunciated by Wheatstone before the British Association in 1835. Since, however, the several facts which he there adduced in support of his proposition were not published, I have deemed it expedient to introduce the simple experiments here given.

Suppose an unscientific observer were to see the Purkinje's figures for the first time accidentally,

* "Science for All," Vol. II., p. 307.

in nine cases out of ten he would be alarmed lest the black branching lines were the forerunners of some disease; and so it often happens that a glance taken under peculiar circumstances is the cause of much fear to one with insufficient knowledge to investigate the matter calmly. Tyndall tells of an artist who came to him troubled by the appearance of vividly-coloured circles. He was in dread of losing his eyesight, because the circles were becoming larger and the colours more vivid; but this alarm was removed on his being told that this very fact pointed out that the disturbing agents were becoming less and less, and would probably be soon absorbed into the system—a prediction which proved correct. When Sir David Brewster was writing the second of his letters on "Natural Magic," he found, upon glancing at a candle in another part of the room, that he could see an image of it *through the top* of his head. Its position with regard to the eye is shown at A, Fig. 9. The image was quite distinct, and as perfect as if it had been reflected from a piece of looking-glass. What could it be owing to? It was evidently reflected from a perfectly flat and polished surface. The eye-brow and the eye-lashes were searched for it. The polished surface could not be found, and the philosopher was driven for a short time to the most uncomfortable conclusion that crystallisation was proceeding within the humours of the eye. This supposition was so unbearable that he set himself down to examine the phenomenon experimentally. He found that the image varied its place by the motion of the head and of the eyeball, or occupied a place where it was affected by that motion. Upon inclining the candle at different angles the image suffered corresponding variations of position, and in order to determine the exact place, he now took an opaque circular body and held it between the eye and the candle till it eclipsed the mysterious image. By bringing the body nearer and nearer the eyeball it was easy to determine the exact position of the reflector. In this way he ascertained that the reflecting body was in the upper eye-lash, and in consequence of having been disturbed the image twice changed its inclination so as to seem to be at B and C (Fig. 9) respectively. Still he sought for it in vain, and not until Lady Brewster had repeatedly examined the spot was the source of annoyance discovered. It was a small bit of wax, about the hundredth part of an inch in diameter, which had lodged between two eye-lashes, a little while before, when he was breaking the seal of a letter. He examined the chip of wax, and found that it was quite competent to produce the effect that had been observed, and there was no doubt whatever that it was the reflector. In order to explain why the candle appeared without the ordinary range of vision, why the images which it formed occupied so mysterious a place as to be seen as it were through the top of the head, he had to make use of the law of visible direction, which we may here profitably stay a moment to explain.

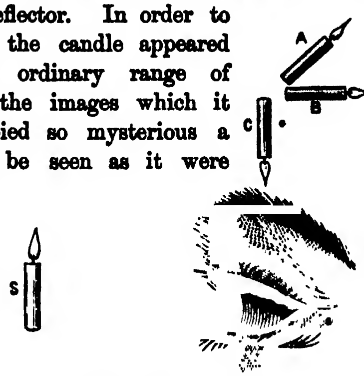


Fig. 9.—Brewster's Illusion.

By means of the refractive media of the eye, objects are projected on to the retina inverted, both perpendicularly and laterally. Some idea of this will be obtained from the accompanying figure (Fig. 10). Follow the course of the external rays from the object to its image on the retina; they cross each other at a point nearly in the centre of the eyeball. This point is called the "centre of visible direction," and the mind judges the position of each particle of the arrow to be somewhere in the direction of the line drawn from its image on the retina through the centre of visible direction—that is, in a direction very nearly perpendicular to the retina at that spot. Now, in the phenomenon under consideration, the chip of wax was situated at *m*, nearly in contact with the cornea, and the light which it reflected passed very obliquely into the eye, falling somewhere about *n*, and appearing, in virtue of the law just explained, somewhere in the direction of a line *n* C.

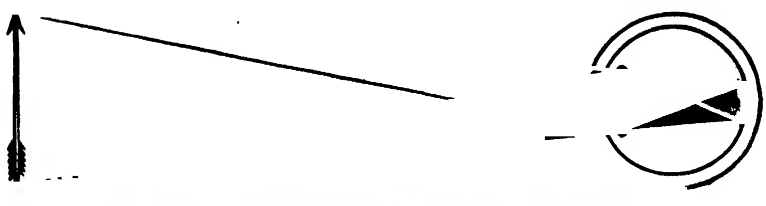


Fig. 10.—Diagram showing how Objects are imprinted on the Retina.

The celebrated Dr. Wollaston was twice afflicted

with an anomalous state of vision. So long as it lasted, he was able to see only half of any object he looked at; thus, upon attempting to read a name on a sign-post only one-half was visible. The explanation of such a queer phenomenon is that sympathetic areas of the two retinæ are inoperative, a condition for serious alarm, or rather, we ought perhaps to say, a condition for consultation with a physician, for such a state has often been the precursor of paralysis.

Now, suppose we turn from this gloomy side of our subject, and take a glance at a distant gas-light with its bars of gold radiating from it. While looking at it a tiny raindrop falls into the eye, and now, if we refrain from winking, we shall see a series of concentric rings suddenly formed (Fig. 11), which gradually grow smaller and smaller until, merging into the light itself, they disappear. A curious sight it is to see a whole succession of lamp-lights surrounded by these contracting rings as you are walking along the street on a dark winter's night, and nothing is so easy as to produce the experiment, for one has simply to face the breeze and allow a raindrop to fall on to the cornea without winking, when the rings are instantly formed and slowly contract. This is one explanation of the phenomenon.* When the globule of rain impinges on the cornea, it spreads out in a series of rings, and the action of these on light is to produce a number of concentric moving light-rings on the retina. Here is an analogous experiment: Drop a stone into clear and shallow water when the sun is brightly shining, a series of out-going light-rings will be seen on the bottom, which are produced by the refractive action on sunlight of the outward travelling wave-rings. And in the eye, if the retina were very near to the lens, precisely the same effect would be observed, and the light-rings would seem to expand. The retina being, however, situated as it is, the rays have crossed long before it is reached, and we get on the eye-screen a series of inverted light-rings. Each of these rings is the base of a hollow cone of light, as will be understood from the foregoing remarks and an inspection of Fig. 12, where *c* represents the lens, and *r* the retina. Now, as the rain-rings spread out on the cornea the cones of light at *a* increase in size; in other words, the common apex at *d* advances towards the retina; the cones of light at *b* decrease in size, and consequently their bases, the rings of light on the retina, appear to contract.

Fig. 11.—A Visual Phenomenon.

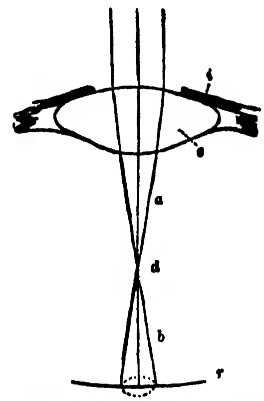


Fig. 12.—How the Rings are formed on the Retina. (*r*, Retina; *c*, Crystalline Lens, *i*, Iris.)

In bringing this paper to a close, we may express a hope that if we have been successful in imparting clear ideas concerning the phenomena herein dealt with, the reader has acquired food for thought a long while to come. The emotional aspect of the eye has not come within our province, and we have accordingly been as indifferent to the flashing glance of a Coriolanus "able to pierce a corslet," as to the melting glance of a Romeo meant to win the favour of a Juliet. We had to confine ourselves to the passionless glance, and have, therefore, considered the eye as a perfect and, under certain circumstances, as an imperfect *instrument*. It will, however, have been evident that so wonderfully is a normal eye constructed, so marvellously do its various parts serve their several ends, that it would be gross presumption in fallible man to find fault with it.

* The writer first described and explained these appearances at the Sheffield meeting of the British Association (1879).

SOME VERY OLD ROCKS.

By Charles Callaway, M.A., D.Sc., F.G.S.

A VISITOR to the Malvern Hills* can hardly fail to notice, that the rocks are very different from almost any others to be found in England. If he travel from London by the Great Western Railway, he will see in the cuttings, first, beds of soft white chalk (Berkshire); next, thin bands of yellowish limestone (Oxfordshire); and then, as he enters Worcestershire, reddish sandstones and clays. He has passed in succession from newer to older rock groups, but the oldest (the Triassic) is but of yesterday compared with the rocks of Malvern.

The first task of most visitors is to ascend the Worcestershire Beacon, the hill overhanging Great Malvern, the highest summit of the chain. Let the geologist take out his hammer, and break off a good clean fragment from one of the bosses which here and there project above the grass. He will see that the rock is something like granite.† He will notice the red felspar, the transparent quartz, and the blackish mica or hornblende. But he will observe an important difference. The three or four minerals, instead of being all indiscriminately mixed together, like the paste, the raisins, and the lemon-peel in a plum-pudding, are arranged in layers. The paste, the raisins, and the lemon-peel—in other words, the quartz, the felspar, and the mica—appear in thin seams, interlaminated with each other, like the leaves of a book. From this resemblance, the seams take their name, *folium*, a leaf; and this arrangement is called *foliation*. The rock will tend to split along the planes of foliation, especially along the folia or "leaves" of mica; so that the surface produced by fracture is frequently glittering with the bright little plates of that mineral. With a little difficulty, the rock may be broken across the planes of foliation. We then see the edges of the folia, which are usually most distinctly indicated by the dark-coloured mica. This rock, which differs from granite only in being foliated, is called *gneiss* (pronounced like the English word "*nice*," with a "*g*" before it).

It is not always easy to make out foliation in small specimens, but it may be distinctly seen on a large scale in many parts of the Malvern ridge, especially near the Beacon, where the lines of dark mica or hornblende, or of the reddish felspar, may be observed running *across* the ridge. This last peculiarity has been described elsewhere.‡

The folia are often very irregular both in thickness and continuity. Sometimes one of the minerals predominates so that the rock is made up chiefly of (say) quartz, when it will be of grey colour; or of felspar, when it will be reddish; or of mica, when it will be dark or even black. Then, too, a band an inch thick will quickly thin out to nothing, or it may keep a tolerably uniform thickness for some distance. The "leaves" may be broad bands, visible in the face of the rock for many yards, or they may be as thin as a single flake of mica. But with all this variation, the one plain fact remains, that the minerals lie in distinct layers, along which the rock will most easily split.

We must clearly distinguish between foliation and the fissile structure of slate and of shale. We have seen§ that slate splits easily along a certain plane because its particles have been flattened by pressure. This *cleavage*, as it is called, does not usually coincide with the planes of original deposition. Shale readily splits up into the thin leaves or layers, in which it was at first deposited. This kind of fissile structure is called *lamination*. But in gneiss a greater change has taken place. This requires careful explanation.

We must first bear in mind that what is now gneiss was once mere mud, or a mixture of mud and sand, deposited in beds, or in thin laminæ, at the bottom of the sea. It has since, perhaps, been converted into slate by consolidation and pressure. But the process does not stop here. Chemistry steps in and remakes the rock. Nature, in her vast laboratory, working with the deliberation of an experimentalist who has unlimited time at her command, can convert a soft clay into a crystalline rock.

Each particle of the clay, or slate, is a compound substance, made up of two or more distinct components, such as silica, alumina,‖ oxide of iron,¶ lime, magnesia, potash, and soda. Of these, silica is the most important. In its simple state it is one of the most widely distributed substances in nature. Quartz is its crystalline form. In union with one or more of the other bodies named, it forms a great variety of minerals, called silicates; with alumina,

* "Science for All," Vol. I., p. 120.
† "Science for All," Vol I., p. 248.
‡ See paper by writer in *Geological Magazine*, May, 1879.
§ "Science for All," Vol. I. pp. 342—346. ‖ Vol. II., p. 302.
¶ Vol. II., p. 45.

and potash or soda or lime, it constitutes felspar; with alumina and less alkali, it becomes mica; without alumina, and with iron or magnesia or lime, or with two or three of these, it crystallises as hornblende: indeed, most of the minerals constituting crystalline rocks are silicates. But how can the quartz, felspar, and mica be made out of mud?

Mud is silicate of alumina, with perhaps some iron or lime and potash or soda. If now we can get the silicate of alumina to take up some potash, we have the materials for felspar, or a variety of mica. If, instead of this, the silicate combines with iron, we may have other varieties of mica; if with lime, other varieties of felspar. Suppose there is some sand in the clay. This sand is simply particles of quartz coloured by iron. If now we can induce the quartz (silica) to unite with the iron, and perhaps some lime or magnesia, hornblende may be produced. We have all the materials in the mud. The problem is, how can we get them to combine?

The act is accomplished in every furnace for the smelting of iron. Clay ironstone is simply hardened mud impregnated with iron. The ore is strongly heated with lime, the iron is separated, and the clay (silicate of alumina) combines with the lime to form slag, a substance which bears some resemblance to hornblende. The slag is glassy, not crystalline. This is due to its rapid cooling. If it were cooled very slowly it would assume the crystalline form.

Our work will be done better if we add water to the heat. Water, more or less heated, is able to change mud into gneiss.

The processes of nature have been imitated in the laboratory. M. Daubrée heated water in a glass tube enclosed in an iron cylinder to prevent bursting through the expansion of the steam. Even at a dull red heat the steam attacked the glass, producing decomposition and recrystallisation of its component parts. Quartz and a silicate were formed. Under similar circumstances, obsidian, "volcanic glass," was converted into crystals of felspar. The same investigator has recorded some very interesting observations, which throw great light upon the origin of crystalline rocks. At Plombières, on the Vosges, and other places in France and Algeria, are hot mineral springs, which the Romans utilised for baths, conveying the water through aqueducts of bricks cemented with lime mortar. By the slow action of the water upon the mortar certain silicates have been formed. Even portions of the bricks, composed of clay coloured by iron, have been converted into crystalline silicates. These changes have, of course, been brought about since the time of the Romans.

These processes, going on quickly in blast furnaces and in the cabinet, and slowly in the old Roman baths, illustrate the mode in which Nature makes the minerals of which gneiss is composed. All the agents she requires are water and heat.

As to the water, plenty of it is always falling from the clouds. Most of it, after carving out mountains and valleys, enters the sea, and, rolling about for a time, returns to the clouds; but a small proportion sinks down into the crust of the earth, not merely into such porous rocks as chalk and sandstone, but into the hardest and most compact. No mineral or rock substance in the earth's crust is absolutely impervious to water. Thus water is supplied to any mass of clay which Nature may wish to change into gneiss.

The heat lies in the earth itself, and the lower down we go the more we get of it.* Assuming that the increase is uniform, the rain-water would be heated up to boiling-point at a depth of about two miles. Other causes, such as pressure, come in to complicate the problem, but it is sufficient for our present purpose to know that plenty of hot water deep down in the earth's crust is provided for the manufacture of gneiss out of clay, shale, slate, or some such rock.

As Daubrée dissolved glass, and redeposited it in crystals of quartz and other minerals, so Nature, with her hot water, operates upon her rock beds. She cannot enclose them in iron cylinders, but she finds them already buried under (it may be) several miles of rock. The heated water, permeating the strata which are to be changed, slowly dissolves the particles of clay and sand. The different constituents are then free to enter into new combinations, according to their respective affinities. These new compounds crystallise as felspar and mica or hornblende, and the superfluous silica, in the form of quartz, fills in the spaces between the other crystallised minerals.

In many parts of the highlands of Scotland is a very beautiful rock, which is like gneiss, but differs from it in the absence of felspar. It is composed of quartz and mica only. The mica is of a brilliant silvery lustre, so that the cleaved surfaces glitter like a piece of silver plate. This

* "Science for All," Vol. II., pp. 110—117, where the question is fully discussed.

rock forms some of the great mountain masses, such as Ben Lomond.

These rocks, which split easily along the "planes of foliation," are called schists, and the last-named variety is denominated mica-schist. It is formed from similar material to that from which gneiss is produced, but containing less alkali (potash and soda).

If the mica bears a very small proportion to quartz, the rock is called a quartz-schist. If mica be absent, we have a rock composed exclusively of quartz. This is named quartzite. Sandstone, which is composed of quartz grains, is not very different from quartzite, since the grains are simply silica, which cannot be decomposed or changed into anything else. The agents which convert a mud into gneiss or mica-schist merely give to the sandstone a semi-crystalline appearance, and, generally speaking, make it harder.

Another rock, found abundantly amongst the most ancient groups, is crystalline marble. This is merely an altered limestone. The calcareous rock, composed generally of fragmentary and pulverised animal remains, simply undergoes the process of crystallisation. By this change all traces of the original organic structure are obliterated, and the chalk or limestone becomes a mass of crystals, and bears a close resemblance to white lump-sugar. This alteration, or metamorphism, to use the technical term, may be artificially produced. If limestone is burnt in the open air, as in the ordinary lime-burning, carbonic acid is driven off as gas, and lime remains behind; but if the rock is exposed to a strong heat in a closed vessel, so as to prevent the passing off of the carbonic acid, no chemical change can take place, and the rock gradually passes into the crystalline state. Marble sometimes occurs as a foliated rock, associated with another mineral, as mica.

Gneiss and some other altered or metamorphic rocks frequently undergo still further changes. Indeed, the great law of change which pervades the universe seems never to be suspended. The solid foundations of the earth, as well as the fragile butterfly and the delicate rose-leaf, can lay no claim to permanence. In granite or gneiss the quartz may be dissolved, the mica, the hornblende, and the felspar may be decomposed. Such changes often entirely alter the already altered rock.

One of the most important of these alterations is the conversion of hornblende into a soft green mineral called chlorite. Some of our very old rocks are thus coloured green.

It was formerly thought that clays, slates, and sandstones were converted into crystalline rocks by the action of intrusive masses or veins. In text-books and diagrams, even of recent date, the gneiss and other foliated rocks are represented as everywhere underlain by granite, which is supposed to supply the necessary heat. But it is now known that, though granite or basalt, forced up in a molten state from beneath, will change the rock in contact, converting limestone into crystalline marble, slate into gneiss, and so on, yet the alteration does not extend far from the intrusive mass. The metamorphism of great formations is due to a more general cause. When strata of mud, sand, limestone, and conglomerate, accumulate to a great thickness, it is supposed that the increased pressure causes depression of a portion of the crust, which is more or less yielding, since it rests on an under-stratum of molten rock. Thus, a series of beds may be so far depressed as to be brought under the influence of a high temperature. Fig. 1 illustrates how this may be done. The diagram represents a section of about two miles of the thickness of the earth's crust, which is here composed of beds of rock which thicken out towards the left. The section is divided into zones of temperature, which, for simplicity, increase by 20° Fahr. each zone, instead of gradually, as in nature. The accumulation of sediment has depressed the conglomerate to a temperature of over 200°, the sandstone to 180°, the clay to 140°, and the limestone to 100°. The lower beds, other things being equal, will be metamorphosed more rapidly than those above. To avoid complexity, the rock beds are represented of enormous thickness, and their thickening out is necessarily greatly exaggerated.

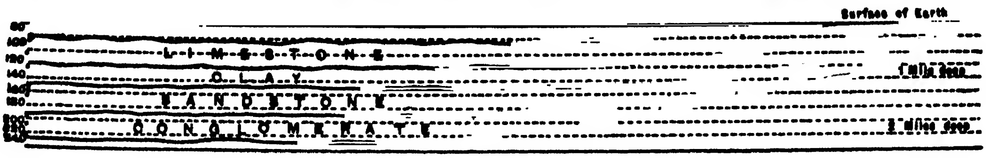


Fig. 1.—Section showing the Thickening of Rock-beds.

A marked feature of many very old rocks is the

excessive contortion which they have undergone. Massive beds of very hard, crystalline quartzite or gneiss, are often twisted and crumpled into the most fantastic forms. It is common to see the

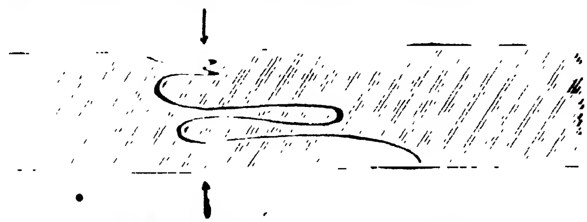


Fig. 2.—Contorted Quartz Vein in a Bed of Schist.

strata bent as sharply as a newspaper which has been folded for the post. This is due to an enormous squeezing power. One little fact, illustrated in Fig. 2, will give the reader some conception of the intensity of the compressing force. The figure represents a vein of quartz, observed by the writer in some very ancient rocks on the coast, west of Rhoscolyn, near the south end of Holyhead Island, in Anglesey. The squeezing force evidently acted in the direction of the arrows, and it is clear that the rock containing the vein has been compressed into less than *one-fourth* of its original thickness. The reader can verify the statement by bending a piece of wire in the shape of the figure, cutting it off, and then straightening it out. Such a marvellous case of contortion is probably without a parallel in the history of science. The island of Anglesey is full of remark-

Fig. 4.—Rock-beds Sharply Contorted. (*After Ramsay.*)

able illustrations of this tremendous squeezing power. Fig. 3 shows in a succession of cliffs how beds of rock, originally horizontal, have been contorted and turned up on end. In the next example, Fig. 4, the pressure has bent the beds into still sharper folds.

The force which has caused such bendings and twistings of the earth's crust has acted sideways. We have already seen (Vol. I., p. 345) how such lateral pressure produced cleavage.

The foliation of rocks sometimes coincides with bedding or lamination, sometimes with cleavage. When the clay or slate is being converted into schist, there is a reason why the crystals, as they are formed, should arrange themselves into folia. The crystals are usually tabular, or they are longer than broad, and they will therefore tend to lie in planes of least resistance. In a rock like granite, where there is neither lamination nor cleavage,

Fig. 3.—Cliffs of Contorted Strata. (*After Ramsay.*)

there is no reason why a crystal should lie in one direction more than another. But in a shale there are planes of lamination, and the crystals will naturally grow in the direction in which there is the least resistance, that is, along the lamination planes. In a slate, on the other hand, the lamination may be obliterated, or nearly so, while cleavage is well marked; so that the newly-forming crystals of mica or felspar will probably lie in the planes of cleavage.

The older rocks, being frequently very hard through the compression and crystallisation which they have undergone, form some of the most prominent scenery in the British Islands. The Malvern Hills consist, from end to end, of highly crystalline rock, of which gneiss, mica-schist, and a sort of granite, are the most abundant varieties. Surrounding the range are

beds of sandstone, shale, and limestone, which, being much more easily acted upon by weather and water, have been gradually washed away, leaving the crystalline nucleus, which was once entirely buried under thick accumulations of sediment, standing up sharp and prominent above

Fig. 5.—Section across the Malvern Chain.

the plain of the Severn. In Fig. 5, A is the crystalline nucleus. On the west side are soft shales B, with two bands of limestone; and on the east are the sandstones, which occupy the valley of the Severn in this district. A very striking example of the same principle is seen in Perthshire, in the giant peak of Schiehallion (Fig. 6). This huge mountain, over 3,500 feet in height, presents from the east or west the appearance of a regular cone. It is mainly composed of very hard white quartz rock, overlain and underlain by much softer schistose beds, and with some bands of schist inter-stratified with it. The superior induration of the quartzite has preserved it from denudation, when the schists were worn and washed away.

In speaking of very old rocks, it is requisite that we should clearly understand what we mean by "old." The geologist is liberal of time; he estimates not by years, but by epochs. But the geological clock is a very rude instrument. It tells us of immense periods, during which continents were raised above the ocean, shaped into mountains and valleys, eaten into by the waves, and worn down by rivers, till a few scattered islands alone remained, and these, in their turn, were destroyed by the never-resting elements. The clock teaches us that within the limits of a single epoch, new types of plants and animals slowly came into life, were variously modified, and passed away. But the clock is unable to measure, even to a million years, the length of the periods during which such changes were brought about.

If the reader will turn to the frontispiece of Vol. I., he will see the order of succession of the rock groups which compose the earth's crust, with special reference to the British Islands, but corresponding, on the whole, to the succession of epochs which make up the history of the earth. Low down in the series is the Cambrian, formerly considered the "bottom rocks" of Britain, because they were regarded as the oldest deposits. But more recently there have been discovered in Europe and North America great formations which are supposed by some to carry the history of the earth as far back from the Cambrian as the Cambrian carried it from the present day. The oldest of these groups was found to occupy an extensive tract of country to the north of the river St. Lawrence, in Canada, and it was thence named the Laurentian. It consists of metamorphic rocks, such as gneiss, mica-schist, quartzite, and crystalline limestone. Overlying this series was a second formation, largely composed of volcanic rocks, called the Huronian. Some other groups have since been described, but these two are well marked and universally recognised. It it now usual to designate these ancient rock groups, of whatever epoch, by the general term Precambrian.

Of late years the Precambrian rocks have received considerable attention in Britain. In the north-west of Scotland, the Hebrides and adjoining mainland, are great deposits of gneiss, highly con-

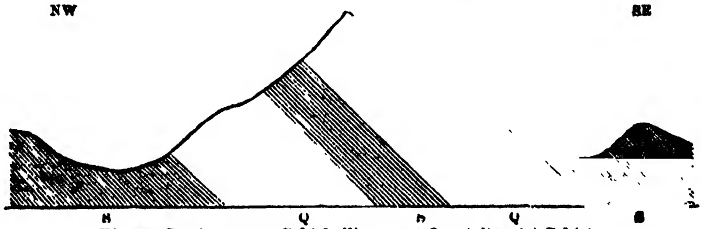


Fig. 6.—Section across Schiehallion. (Q) Quartzite; (S) Schist.

torted, which were called at first the "fundamental gneiss," and more generally the Lewisian or Hebridian. This group is the probable equivalent of the Laurentian. The Malvern Hills are composed of similar rocks, and it is very likely that they are of the same age. The ridge on which St. Davids stands, and a part of the ridge which, rising above the town of Caernarvon, strikes north-east towards Bangor, though made of somewhat different deposits, are probably of about the same epoch. The best exposure of these ancient rocks in South Britain is in Anglesey, where masses of contorted gneiss, grey and dark green, pass up into a granite-like rock, similar to that which forms the ridges at St. Davids and Caernarvon.

A second Precambrian group has also been discovered in Britain, called the Pebidian. Like the Huronian, which it possibly represents, it is a volcanic group. It consists of lavas, ashes, &c., materials identical in character with the most

modern volcanic eruptions. This is a very interesting point, since it proves that the forces of nature were the same in kind in these very ancient epochs as at the present day, and there seems no reason to believe that they differed in intensity. These rocks were first noticed at St. Davids by Dr. Hicks, and they have since been observed in Caernarvonshire, Anglesey, Charnwood Forest, and Shropshire. The well-known Shropshire mountain, the Wrekin, near Shrewsbury, exhibits rocks of both the Precambrian epochs.

It must not be supposed that highly crystalline rocks are confined to the Precambrian periods. Gneiss, mica-schist, marble, and other highly altered

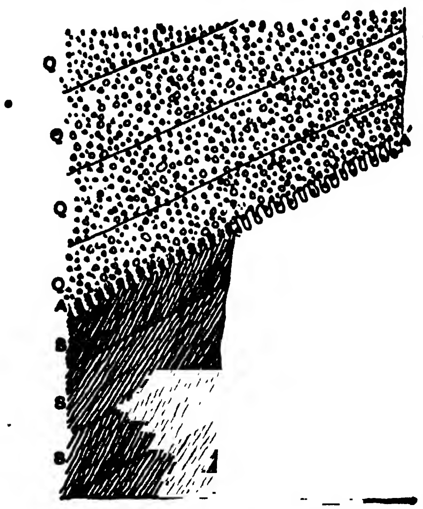


Fig. 7.—Contorted Ripple-marks in the oldest Rocks in the World. (Q) Quartzite; (s) Schist. Scale, one inch to a foot.

deposits may occur in much younger groups. Clays, sandstones, and other sediments of any age, will be metamorphosed, if the necessary conditions are supplied. A large portion of the Highlands is occupied by gneiss, mica schist, and quartzite, supposed to be of Lower Silurian age. In mountain ranges such as the Alps, strata of still newer epochs are converted into crystalline schists. There is no reason why gneiss should not be forming at the present moment; but it is evident that we can have no positive proof of the fact. The process would be going on at the depth of perhaps several miles; so that before the gneiss can see the light of day, there must be upheaval to that amount, and the superincumbent strata must be stripped off by denudation. For this reason we are not likely to discover metamorphic rocks in any of the newer formations.

Within the year 1879, there has come under the notice of the writer a very remarkable illustration of several of the principles expounded in this paper. It was observed in Holyhead Island, near the spot where the intense contortion described and figured on p. 203 occurs. A cliff of quartzite, with a soft schist at the base, faces to the south. The quartzite

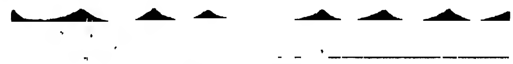


Fig. 8.—Ripple-marks.

and schist are in beds, which dip to the north. The schist has been worn away by the waves, leaving the lowest bed of quartzite projecting like a cornice, but sloping inwards. On the lower surface of the quartz rock are numerous rounded projections, roughly represented in Fig. 7. The surface A A′, strange to say, is simply the cast of a surface of mud, which had been rippled by the waves of the sea. The sea-shore, whether composed of sand or mud, is often seen to be shaped by the tippling of the water in the manner shown in Fig. 8. If this surface be covered in with sand, it is evident that the surface of the overlying bed will be shaped as in Fig. 9. If now an enormous squeezing force, acting in the direction of the arrows, compress the bed into about one-fourth of its original bulk, the rounded projections will be squeezed up, as in Fig. 7. The compression is so great that some of the projections are brought into actual contact, and squeezed into each other. Then the mud is metamorphosed into a soft schist, and the sandstone into quartzite.

This single illustration proves the following principles:—(1) In the very earliest epoch of which we have any knowledge, the ripples of the sea produced the same effects as at the present day. The laws of nature, in their gentleness as in their force, have not changed. (2) The momentary movement of a wavelet has been preserved in rock through the great succession of epochs of which

Fig. 9.—Cast of Ripple-marks.

geology preserves the record. Nature does not despise or forget the most trivial cause. (3) The ordinary mud and sand of our coasts may be converted into crystalline rocks. (4) The rocks which compose the earth's crust are sometimes subjected to enormous pressure, producing excessive compression and distortion.

Our concluding inquiry is, What was the population of the earth in these early periods? Is it likely that the world was void during a long succession of ages? We have seen, from the teaching of the wave-marks, that during the Precambrian

Fig. 10.—Fragment of *Eozoön* (Nat. Size). (*After Dawson.*)

epochs, the conditions of sea and land were not widely different from those which now prevail. Why should not fish have sported amidst those rippling waters, or why should not birds and four-footed creatures have left the imprint of their feet upon the smooth surface of the mud?

In reply to these questions, it may first be observed that all the evidence hitherto collected tends to prove that such highly-constructed beings as fish, reptiles, and birds did not come into being till much later periods. Fish are first known in the Silurian, reptile-like forms in the Carboniferous, and birds not earlier than the Trias. The life of the Cambrian period is not very advanced. The most conspicuous forms are Trilobites (Vol. I., p. 346), beings which do not rank so high even as a

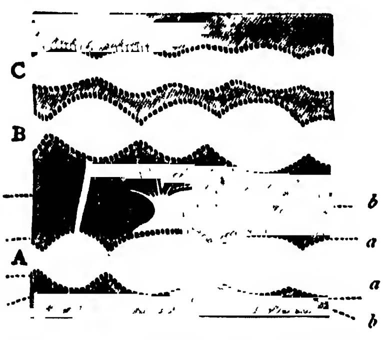


Fig. 11.—Section of Eozoön. (*After Carpenter.*)

crab or lobster. If, then, we choose to picture to ourselves the condition of the animate world in the Laurentian period, we shall violate probability if we tenant the sea with fish, the earth with reptiles and mammals, and the air with insects and birds.

As to plant-life, there is no reason to believe that, if plants existed, they had risen higher in the scale of complexity than the lowly sea-weed.

In looking for fossils in these ancient deposits, we are met by a great difficulty. The Laurentian rocks are highly "metamorphosed." If the original sediments contained the remains of shells, corals, or sponges, the conversion of the beds into gneiss, mica-schist, and other crystalline rocks would, under ordinary circumstances, obliterate all traces of the fossil. There is, however, no reason why the traces or remains of animals should not be preserved in quartzite and limestone. In Silurian quartzites the tracks and burrows of worms are not uncommon, but no evidence of life has yet been discovered in quartzite of undoubted Precambrian age.

With limestones the case is somewhat different. In the Laurentian rocks of Canada, a structure has been discovered which such eminent scientific men as Principal Dawson and Dr. W. B. Carpenter believe to be an animal, and Dr. Dawson has conferred upon it the name of *Eozoön Canadense*, or the *Canadian Dawn-animal* (Figs. 10, 11, 12). This creature

Fig. 12.—Portion of one of the Calcareous Layers of *Eozoön*, magnified 100 diameters. (*After Carpenter.*)

(*a a*) The proper Wall of one of the Chambers, showing fine Vertical Tubuli, with which it is penetrated, and which are slightly bent along the Line *a' a'*; (*c c*) the intermediate Skeleton.

is supposed to be closely allied to the *Foraminifera*, which are animals of the simplest structure, composed of a mere globule of a jelly-like substance, which resides in a minute shell, perforated with holes (*foramina*, hence the name *Foraminifera*). Through these holes the animal protrudes numerous filaments of its substance. These microscopic shells sometimes make up vast rock-masses of chalk (Vol. I., p. 14, and Vol. III., pp. 79, 80). In *Eozoön*,

the animals are grown together in a colony, as in a sponge or compound coral.

Fig. 11 is an enlargement of a small section of the fossil. A, B, and C represent the chambers (three tiers in this specimen) occupied by the animal. They communicate with each other by narrow apertures, one of which is shown at *c*; *a a* are the walls bounding the chambers, and they are perforated by foramina, like the shells of those simple foraminifera to which allusion has already been made; *b b* represents the intermediate skeleton, and at *d* is seen a set of ramifying tubes. The chambers A, B, and C, originally filled with the jelly-like *Eozoön*, are now occupied by serpentine, and the intermediate skeleton, originally limestone, is now crystalline marble.

Eozoön, if truly a fossil, is by far the oldest known animal, and in its structure is simplicity itself. It stands at the beginning of the known chain of life Man at the end.

THE CESSATION OF LIFE.

By Robert Wilson, F.R.P.S.,

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"DEATH," says Jeremy Taylor, "meets us everywhere, and is procured by every instrument, and in all chances, and enters in at many doors; by violence and secret influence, by the aspect of a star, and the stink of a mist, by the emissions of a cloud, and the meeting of a vapour, by the fall of a chariot, and the stumbling at a stone, by a full meal or an empty stomach, by watching at the wine, or by watching at prayers, by the sun, or by the moon, by a heat or a cold, by sleepless nights or sleeping days; by water frozen into the hardness or sharpness of a dagger, or water thawed into the floods of a river; by a hair or a raisin, by violent motion or sitting still, by severity or dissolution, by God's mercy or God's anger, by everything in Providence, and everything in manners, by everything in chance, and everything in nature. *Eripitur persona, manet res*; we take pains to heap up things useful to our life and get our death in the purchase; and the person is snatched away whilst the goods remain. . . . . The chains that confine us to this condition are as strong as destiny, and immutable as the eternal laws of God." The fact that death thus comes to us all sooner or later, and that in its coming it may sever the thread of life without a minute's warning, has naturally prompted thoughtful men in all ages to scrutinise closely not merely its phenomena, but its causes. Although there is probably no other subject which has to a greater extent stimulated reflection, and which men of science have pondered in their minds more carefully, there is hardly any about which it has been harder to set forth accurate and exhaustive collections of fact, or just and adequate explanations thereof. Without going into a review of the myriads of conflicting opinions which have been broached as to the act which marks the close of life, it may be said that certain signs of death are very easily recognised. These may of course be referred to the conspicuous activities of the living body, those of which movement, heat-giving, and sensibility are the most noteworthy manifestations. If, however, we understand death to consist in the cessation of the vital energies of the body, it is necessary to study the cause of their continuance ere we can arrive at a proper conception of that which brings about their stoppage. The rudimentary conditions of life in a body are of course to be found in a certain stream of changes that flows through its parts. These parts grow and waste and grow again. If the waste be progressing more rapidly than the regrowth, naturally a time comes when the organic changes, which support vital activities, cease, and thereupon it may be said that death supervenes. The life of any organism is made up of a series of interchanges between it and its surroundings, interchanges in virtue of which it assimilates from its environment that which is necessary to sustain it, throwing back into the medium in which it exists whatever portions of its substance it has broken down in the wear and tear of activity. At different periods the relation between the two sets of operations varies, and when the wearing exceeds the repairing by a certain proportion, life is extinguished. In two ways may this be brought about. Through long use the power of assimilation and regrowth may become so enfeebled that a living organism cannot extract from its surroundings what is wanted to keep it sound and vigorous. Or it may be that whilst the

recuperative faculties are strong enough, the organism's environment is devoid of the matters which are wanted for rebuilding its body. To use a familiar illustration, a man may starve in the midst of plenty because he cannot digest or assimilate his food. Another whose digestive and assimilative powers are in excellent working order may die of inanition, simply because he has within his reach everything but food.

"Life," said the late Mr. G. H. Lewes, "is possible only under the necessary conditions of an organism on the one hand, and an external medium on the other. It is the mutual relations of organism and medium which determine the manifestations we name life." In the same way we might say that the real cause of death is some cardinal dislocation between the relations of organism and medium, and that the causes of death are susceptible of twofold division into those outside and those inside the organism. There is the waste impairing the power of the body to feed itself. Then there is the constant absorption from the body's surroundings of nutritive matters, which are year after year themselves modifying the composition of the various organs of the frame, and not seldom depressing their ability to repair structure broken down in action. The process here suggested is cumulative in its effect, and as it goes on it produces the changes made outwardly visible in old age, changes which end in that "bursting of the bubble" life in the sea of eternity to which Lucian has finely likened the terminal act of death. Death, then, is not the enemy and destroyer of life so much as its natural outgrowth or residue, for with its oncoming, though certain modes of existence are terminated, certain others are begun. A fair definition of death is this. It is the disruption of that relation between an organism and its medium, and between the various parts of an organism one with another, which not only enabled the organism to live, but also enabled each of its parts to work helpfully and harmoniously with the others. That there must be more than a mere disruption between the organism and the medium in which it lives to produce death is proved by cases of "suspended animation." The frozen frog is separated from the surroundings necessary to its life, yet it is not the victim of death, for if thawed and put in fluid again it will live. Had, however, the relation of the various parts of which it is formed been so altered that they no longer played into each other, then of course life would not have returned after the congelation of the creature. From what has been said it will not be difficult to infer that as there are two kinds of life in the body, so are there two kinds of death. One life is that which is made up of molecular changes of wearing and repairing in the tissues or rudimentary parts of organisms. Another is that which consists in the harmonious play of these parts in conjoint working, a kind of life constituted by those bodily activities that keep up a material interdependence between the several portions of an organic whole. When we strike a blow, or even think a thought, we break up some molecules that build up our muscles or brains—in other words, we draw upon or spend a certain quantity of our store of molecular life, which is instantly replaced by a fresh supply. This spending, breaking up, or "molecular death," is the necessary condition of all functional activity—an ideal dimly present to the mind of some of the old English divines, like Bishop Taylor, who, in his quaint treatise on "Holy Dying," says "Every day's necessity calls for a separation of that portion which death fed on all night, when we lay in his lap and slept in his outer chambers. The very spirits of a man prey upon the daily portion of bread and flesh, and every meal is a rescue from one death, and lays up for another; and when we think a thought we die, and the clock strikes, and reckons one portion of eternity; we form our words with the breath of our nostrils, and we have the less to live upon for every word that we speak."

But in addition to this kind of death, there is general death—a death of the system—systemic death as it is often called, which consists in the breakdown of that essential and harmonious interdependence of the various organs of the body, essential to the continuance of molecular life. For example, the supply of blood to the body of a man is essential to the maintenance of life; and the connection between the apparatus which circulates blood, and the nerve centres, is essential to the working of that apparatus. If we sever that connection, or in any other way destroy the action of the heart, we stop the blood-supply, and soon produce systemic, or general death, although, in the remote parts, and in the minute elements of the tissues, a considerable amount of molecular life may, for a little while afterwards, continue to flicker feebly. Again, if by any chance, the minute component parts of an organ die, as is seen in the case of a finger or toe subject to gangrene, that limb may, from molecular, or local death, actually rot away, without producing general systemic

death, or death of the body as a whole. There are, however, certain particular organs, vital injury to which does produce not merely local and molecular death in the long run, but systemic or general death almost at once. These, as might be inferred from what has gone before, are organs on whose mutual inter-action, on whose harmonious working with the body as a whole, and with each other as parts, systemic life, or the vital unity of the organism, depends. The structures in question are those concerned in the functions of respiration, circulation, and innervation, or the storing and distribution of nerve-energy. Thus it is that Sir Thomas Watson used to describe life as resting on a tripod, with lungs, heart, and brain for its three vital supports; and thus it was that Bichat taught that the mode of dying might begin either at the heart, lungs, or brain. But it must be confessed that brain, heart, and lungs stand to each other in such close mutual inter-dependence, that in practice it is hard to say that in every case of death one and only one is primarily concerned. Each is by injury affected in two ways: directly itself, and then indirectly, as the result of its injury, upon the others. For example, where the hurt that has produced death has been first of all one that fell upon the brain, we must keep in view that the cessation of vitality in the brain, or nerve-centres, through the nerves that connect it with the respiratory and circulatory systems, effects a derangement in their working, that in turn re-acts on the brain. By injury to that portion of the brain from which come the nerves that supply the muscles of respiration, breathing is hindered, if not stopped. The blood is therefore not properly oxidised and purified, and both brain and heart being therefore supplied by blood that is not oxidised and pure, have in turn their functional activity impaired and ultimately destroyed. In the same way a fatal wound of the heart, by depriving the other two organs of their blood-supply, kills them. Indeed, such is the interlacement of working in the three organs in question that although the real cause of death is injury to one, what Bichat calls the mode of dying is made manifest through the functions of another. A man may die, to all appearances, from suspension of the activity of the lungs. Yet, on examination, it might be found that it was not any injury to these structures that produced death, but, in reality, an injury to the brain or spinal marrow which supplied the breathing apparatus with that nerve power which is one of the essential conditions of its working. Hence it is that when a surgeon is confronted with a case of spinal fracture ("broken back"), the breathing of the patient is one of the first things he looks to. If respiration is seen to stop suddenly after the injury to the upper part of the backbone, the surgeon at once infers that the breakage is somewhere in the neck above the point from which what are called the "phrenic nerves," or those that supply the respiratory muscles, emanate. Roughly speaking, the mode of dying may be distinctively set forth thus:—When the fatal injury strikes the heart, death is said to be due to *syncope*. If the lungs are the seat of the death-blow, death is said to be due to *asphyxia*. If the brain be primarily attacked, death is said to be due to *coma*.

Generally speaking, all the energies and activities of the living body are traceable to processes of tissue-oxidation. The breakdown of the tissues of organs is the manifestation of work, and it is always associated with their decomposition through union with the oxygen, carried to them from the lungs by the red corpuscles in the blood. A certain broad classification of the causes of death has therefore been based on this idea. General, or systemic, as well as molecular or local death, may in the long run be said to be referable to hindrances in the way of oxidation of tissue. A want of material to be oxidised, or of the inorganic substances essential to the maintenance of that material in proper oxidisable form, the failure of a due supply of adequately oxygenated blood (blood capable of carrying on the oxidising process), and the absence of the chemical conditions essential to that process, will all bring about both general and local death, which latter is often called "mortification," or gangrene. But it must again be insisted on, that the presence of any one of these hindrances to oxidation soon brings the others into active operation—so closely bound together are they all in their working. Taking the first of the general causes of systemic death, deficiency of material to be oxidised, we may say that it is but seldom the most obvious cause of death. Impaired nutrition leads to a diseased condition of one of the three great vital organs, heart, lung, or brain, whereupon it first works with difficulty, and ultimately ceases to work at all, thus bringing about death. Although some maintain that death from hunger is due to the loss of animal heat in the first instance, yet there are others who hold that the want of material in the starved body for oxidation causes cessation of the heart's action, which is thus the near, though not the remote cause of death.

With regard to death which is due to a defective supply of oxidised blood, more must be said. There may be an absolute depletion of the blood throughout the body, owing either to one of the great vessels having been opened and fatal hæmorrhage ensuing, or to a complete breakdown in the propelling organ—the heart. The want of arterial blood, too, flowing into the heart, deprives it of its natural stimulus to contraction, and the sufferer perishes from syncope. The circulation of the blood may also suddenly come to a standstill, and thus cut life short. For example, the main arterial trunk of an organ may be closed either by a ligature, or by a clot, or the veins in another organ may be stopped up, the result being the local death of both organs, and, if they or either of them be vital, the general death of the body as a whole soon after. A cause of sudden arrest of the circulation and, therefore, sudden death, is pressure on the heart or great vessels leading to or from it, a pressure which may be due to a tumour growing in the chest cavity. The sudden stoppage of the action of the heart itself, which produces death, may be due also to a blocking up of the "coronary arteries" which supply the tissue of this organ with blood, for, of course, when deprived of oxidising material the heart ceases to live and act. Again, the heart may cease to beat because of irritation—that is to say, over-stimulation of that part of the nervous centres from whence spring nerves which "control," or exercise an inhibitory power over, the great blood-pump. In such a case it is supposed the "control" becomes pressed so far as to destroy action altogether. In either case, however, the prominent fact is, that the heart is so injured that it ceases to propel blood throughout the body, and death is due to a defective supply of the vitalising fluid. Then, although there may be a plentiful supply of blood, it may be of the wrong kind. In other words, the blood circulated may be imperfectly oxidised; and, therefore, for practical purposes, may rank as no blood at all.

An impure blood-supply may originate in a great variety of ways. There may be either some obstacle to the absorption in the blood of oxygen breathed from the air into the lungs, or the air breathed may not have a proper amount of oxygen itself. In either case we are apt to have death from *asphyxia* produced. Familiar illustrations of these two methods of death are closure of the pulmonary passages by the hangman's cord, by drowning, by pressure from tumours in the chest or throat, by spasmodic contraction of the narrow slit in the top of the windpipe, called the glottis, or by destruction of the tissue of the lung itself by consumption. Then, again, another cause of defective oxidation, which in turn produces death by *asphyxia*, is an arrest of the respiratory movements in virtue of which blood is oxidised by air being breathed into the lungs. One common cause of this is some injury to the respiratory nerve-centre, the "medulla oblongata," where the nervous supply for the organs of respiration emanates; and this injury may be caused by disease of the nerve-tissue, or by defective supply of oxidised blood to it, or by the supply being impregnated with a paralysing poison such as chloroform. Spasmodic contraction, or fixture of the muscles of the chest, caused by the disease known as *tetanus*, or "lockjaw," or produced artificially by strychnine poisoning, will also, as will mechanical pressure on the chest, put a stop to the movements of respiration. Death will thus be caused by a hindrance to the entrance of oxygen, and therefore of a proper supply of oxygenated blood to the tissues of the body at large. The supply of oxygen may also be cut off by a process of expulsion, that is to say, the victim may be consigned to an atmosphere in which the place of oxygen is gradually taken by another gas. A familiar illustration of death so caused is suicide by means of charcoal fumes. Every crack and crevice that might admit air is carefully stopped up in the suicide's chamber, and the brazier of charcoal lit. As combustion goes on, carbonic oxide or "carbonic acid gas" is gradually evolved. It takes the place of the oxygen in the atmosphere of the room, which is consumed, first by the victim, secondly by the burning charcoal. As carbonic oxide and carbonic acid are left, and as neither is a supporter of life, death by suffocation is the speedy result. With regard to death due to interference with the conditions necessary for the oxidising processes, very little is known. It may be conjectured that even when there is enough of material ready to be oxidised, and plenty of blood ready to oxidise it, the oxygenating process will not go on in the absence of certain other conditions. A given mean temperature of the body is one of these, and any very great rise or fall in the normal temperature of the body most assuredly produces death. In other words, such alterations of temperature are incompatible with the carrying on of that chemical interchange between the body and the oxygenated blood which is essential to life.

As regards the signs of death, distinction may be made between apparent death and real death.

Apparent death is marked by symptoms which follow cessation of the action of heart, brain, and lungs. Real death is indicated by something more, namely, arrest of nutrition and absence of contractility, and the commencement of decomposition. In all ages a belief has prevailed that it is so difficult to distinguish real from apparent death that people run a certain risk of being buried alive. No doubt in hot countries, where by law interment must take place within a few hours after life has passed away, this risk may not be altogether imaginary, and many stories of premature interment have in such places been put on record. The state of trance is, as we all know, suspiciously like death, and though it is not death, one suffering from it may be buried by a mistake. Sir Claude M. Wade gives an account of an Indian Fakeer who was buried in an underground cell for six weeks under strict guardianship, and who, on being twice during that time exhumed by order of Runjeet Sing, was found with his body in precisely the same position as it was when interred. Stranger still, he was restored to life again when finally dug up. Lieutenant Boileau, in his "Tour through the Western States of Rajwarra," tells a story of a native who was brought to life after being immured for ten days in a grave lined with masonry, and covered with huge slabs of stone. In both cases when the bodies were brought to the surface their appearance was corpse-like. A patient of Professor Louis was said to have been found the day after her supposed death in such an attitude as led that eminent physician to conclude that she had recovered, and died in struggling to free herself from her winding-sheet. But this inference is strained, because it would be quite possible to account for the altered position of the body by movements due to the evolution of gases within the body itself, to which cause are also to be traced the changes in position which have led credulous persons to affirm that the bodies have turned in their coffins after they were put under ground.

But with regard to all such exceptional instances we may say that only gross carelessness could confound real with apparent death. The one is to be distinguished from the other by signs due, not merely to cessation of vital and organic functions, but to certain changes in the tissues that are incompatible with life. Of course, loss of sensibility is not in itself a trustworthy indication of death. But arrest of respiration followed—not preceded—by stoppage of circulation, and that in turn followed by loss of sensibility, affords tolerably safe proofs of real death. The only fallacy that taints this kind of evidence is that respiration and circulation may be so reduced to a vanishing point, as in trances, that we are unable to detect their operations, or distinguish between the minimum of their activity and their total annihilation. Laborde has proposed as a test of death that in cases of doubt a needle should be plunged into a muscle and kept there for twenty minutes. If on withdrawal it is bright, life is extinct. If, on the other hand, it is rusted, that is, coated with oxide of iron, the inference is that oxidation is going on and that "molecular life" is still flickering in the body experimented on. A rough-and-ready test is to tie a thread tightly round one of the fingers of the body. If below the ligature the tissue reddens, life is still present. If it does not redden, death has set in.

But of all the changes wrought by death in the bodies of the higher animals there are four which are eminently characteristic. These are absolute loss of muscular contractility and animal heat, rigidity, or *rigor mortis*, and putrefaction. The loss of muscular contractility must, however, be absolute to be trustworthy. The muscles should refuse to contract even when electricity is applied to them, and it must be kept in view that it is not till some variable time after death has occurred that this vital property of muscle is lost. After the muscular system loses its contractility, the next, and one of the most infallible evidences of real death, is the *rigor mortis*. In this condition every muscle in the body is, within from one to twenty hours after death, stiffened and contracted in length, and so it remains for from twenty-four to thirty-six hours. With regard to the cause of *rigor mortis* a great conflict of opinion has existed for many years. It is known that whenever a muscle is removed from the blood-current, or when it is cut out of the body altogether, it passes into this condition just before it begins to decompose. Heat appears to hasten the on-coming of *rigor mortis*, and cold retards it. If the circulation can be kept up in a dead muscle artificially the rigor will be deferred. If, however, the blood so injected contains no oxygen it will come on as usual; hence the presence of oxygenated blood in the muscular tissue prevents the rigor from setting in. As to the actual condition of the tissue itself during the death-rigor, the most generally accepted view is that the minute hollow fibres, or tubes, of which muscle is composed, have their contents coagulated, and that the "clot," like that of blood,

A DISEASED POTATO.

By Worthington G. Smith, F.L.S., M.A.I., etc.

POTATOES have probably for an almost incalculable time been subject to the destructive murrain popularly known as the "potato disease." The murrain is by no means confined to the edible potato, for it attacks various members of the potato family. Of late years the tomato has been so badly attacked by onslaughts of the murrain of the potato, that in many quarters tomato-culture has been rendered impossible; time after time the entire crop has been swept away by the distemper. Neither does the potato disease confine itself to the large family of plants (*Solanaceæ*) to which the potato itself belongs, but it attacks and destroys different members of several allied orders of plants. Nothing can be more fallacious than the supposition that the potato disease is of comparatively recent origin; plants suffered from very similar diseases when the entire conformation of the world was quite different from what it now is. Even in the remote carboniferous epoch of geologists plants were affected by a similar malady, for fossil plants have been found in the coal measures with their tissues corroded and disorganised by a fungus hardly to be distinguished in external characteristics and microscopical details from that which causes the potato disease of the present day.

The year 1845 is memorable for a terrible acceleration of the murrain over England, and indeed over the whole of Western Europe; and this acceleration was led up to step by step during many previous years. In 1830 German potatoes were attacked by rot, and in 1844 the disease was sufficiently developed in Belgium for Dr. Morren to describe its nature. In 1844 the potato murrain appeared in its most virulent form in Canada and the northern parts of the United States.

At the time of the outbreak in England it was a commonly received opinion with agriculturists that the disease amongst potatoes was owing to the use of Peruvian guano. This opinion, however, received no support from men of science, and it has no support now, although some farmers at the present day are inclined to favour it. There may possibly be a grain of truth after all in this curious old idea, for it is now well known that the secondary condition of the fungus of the potato disease hibernates best in a material like guano, especially when that material is in the "greasy paste" condition so often described in works on the Guano Islands. From 1841 to 1851 more than one million tons of guano were imported to this country alone from the Chincha Islands; in other words, the guano came from near the immediate home of the potato plant and the home of the potato fungus, for the fact is undoubted that the murrain and its accompanying fungus are naturally exotic, like the potato itself. Potatoes being exotic, they of necessity lead in temperate climates a somewhat artificial life; they have to be nursed and carefully looked after; consequently the murrain easily gets a stronger hold upon them than it does on the hardy wild plants of our hedges. As an example of this, reference may be again made to the tomato, another tender plant which with us has to be nursed. The potato disease will spread from the tomato to the potato and from the potato to the tomato with great rapidity and with deadly effect, whilst the robust near relation found in our hedgerows, the common bitter-sweet (*Solanum dulcamara*), will resist the disease, or if infected will throw it off with ease; the latter plant is hardy and has a strong constitution, whilst the two former are delicate and succumb at once. If, however, the potatoes and tomatoes are grown in greenhouses with an unvarying temperature they seldom fall victims to the murrain; they are then, in fact, like delicate persons kept indoors, out of cold, fog, and infectious matter.

At the present day every person knows something of the external aspect of diseased potatoes. Persons who live in towns know the diseased tubers, as they are sometimes placed upon the table; house-wives know bad potatoes by their corroded and brown inner substance, and cooks with sharp eyes know the disease in a moment by a slight discolouration of the superficial skin of the tuber—a discolouration also well known to farmers, agricultural labourers, and those botanists who have made a study of vegetable pathology. Dwellers in towns are less familiar with the murrain of potatoes as seen in our cultivated fields; potato growers detect the flagging of the first leaves, the appearance of black spots on the foliage, and a faint putrid odour belonging to the decaying plants. The attack of the murrain is often so rapid as to keep growers of large quantities of potatoes in a state of continual

nervousness. A field of apparently healthy plants of one day may succumb the next, and every plant be prostrate on the ground. This is frequently equivalent to a loss of many thousand pounds to a single individual.

The annual average commercial value of potatoes in Great Britain is more than £13,000,000, and the loss from the murrain is often 50 per cent.; by these figures some idea may be obtained of the magnitude of our annual losses. One would think from a consideration of circumstances like these that some conference of competent botanists might be held with advantage, and some steps be devised to stay the ravages of so terrible a destroyer. Our cultivated fields are now quite as much neglected as our streams and rivers were in former times. Badly cultivated places swarm all over the country, and these places are in many instances the hotbeds of the diseases which afflict our culinary plants and cereals.

The potato murrain is commonly at its worst during or soon after the storms of midsummer or early autumn; it spreads with deadly rapidity during close, "muggy" weather, when the fields are half hidden with mist or wet with warm rains. One first sign of incipient disease (lurking within the tissues of a potato plant) is an unusually dark green colour of the leaves. This deep tint is often a certain indication of a coming bad attack of disease. When a virulent attack of the distemper descends upon the potatoes, the bushy green plants of one day may be leafless the next, and nothing left above ground but blackened stalks. In a more moderate attack of the murrain the leaves will be blotched and distorted, and the blackened patches will be covered with a delicate and very fine white bloom. This bloom is much finer than the down which grows upon the potato plant itself, and is in appearance not unlike the bloom or mould so commonly seen on stale paste or jam, but still it is finer in all its parts and altogether more delicate in appearance. This fine and almost invisible bloom is the "fungus" of the potato disease. It invariably accompanies the disease, and every competent observer considers the fungus to be the *undoubted cause* of the disease itself.

With the foregoing remarks we may leave our brief history, statistics, and account of the external aspect of the potato murrain, and address

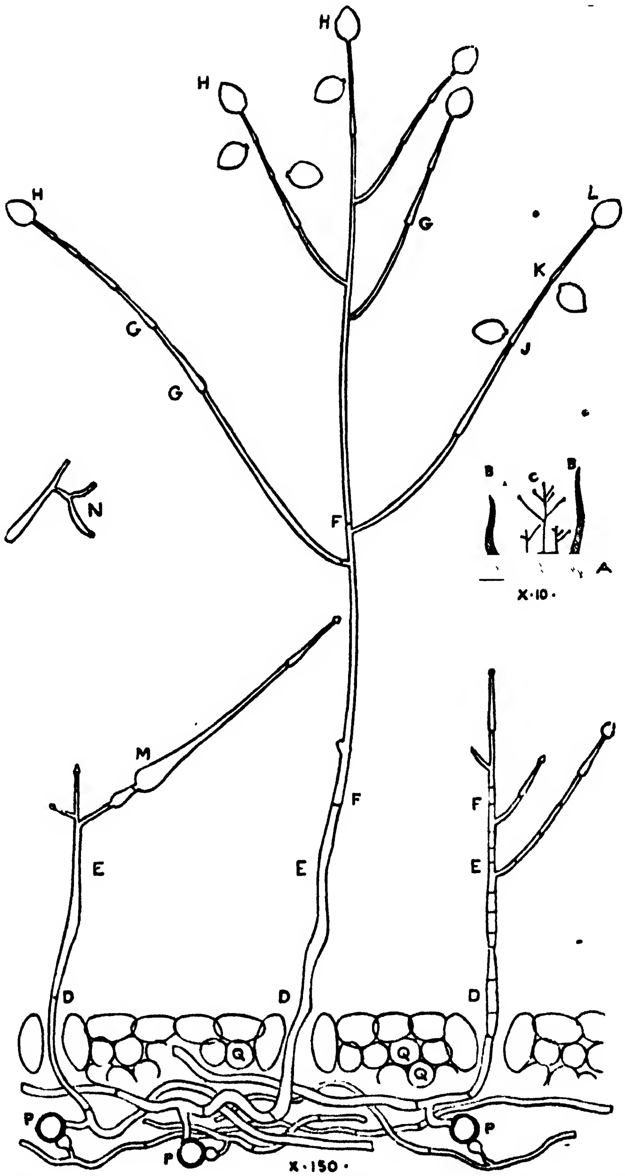


Fig. 1.—Fungus of the Potato Murrain (*Peronospora infestans*) emerging from the stomata or organs of transpiration of the Potato leaf. (Enlarged 150 diameters.)

selves to a close examination of the disease itself as revealed to us under the higher powers of the microscope.

We will take a diseased leaf on which there is one of the well-known dark discolorations, with its accompanying white bloom. If we look at this

bloom with a very strong lens we shall still see nothing but a fine bloom, ten or twenty times finer than the hairs belonging to the leaf of the potato plant. So small is the bloom, or fungus, in all its parts, that though every thread is branched and ramified like a tree, yet it commonly happens that the height of the fungus above the leaf is less than the thickness of the leaf itself. At A, Fig. 1, is shown a minute portion of a potato leaf seen in section and magnified ten diameters. A shows the thickness of the lamina of the leaf; B B, hairs on the leaf; C, three sprays of the fungus. This small diagram will give an idea of the extremely minute proportions of the fungus we are now dealing with.

As very little can be learned from an examination of the potato fungus with an ordinary lens, we must seek the aid of the microscope for further magnification. When a somewhat high power is used—150 diameters—the fungus of the potato murrain stands before us as in Fig. 1. The fungus has had more than one name, but it is now universally known as *Peronospora infestans;* it is colourless, and its appearance under the microscope is like spun glass and transparent; its ramifications or roots are within the potato leaf, between the upper and lower surfaces, and the sprays of the fungus grow out of the mouths or organs of transpiration of the leaf. The structure of leaves, with their stomata, or mouths, has already been explained,* so that nothing further regarding the physiology of the leaf need be adverted to here. At D, D, D, in Fig. 1, may be seen the mouths of the leaf in section, and, emerging from the inside of the leaf outwards, the sprays of the fungus, E, E, E. As the sprays grow, joints or septa appear in the threads, as at F, F, F, and minute branches are thrown out in all directions from the main stem of the fungus; these branches temporarily and repeatedly rest, as at G, G, G, and when the growth is continued the new piece swells at the base, G, G, G, as if in an attempt to form one of the apical swollen conidia, spores, or seeds, as at H, H, H. A terminal spore has been formed at J, but the renewed growth ot the fungus thread has pushed it off, and the stem of the parasite has then grown on to K. The spore, K, has been again pushed aside by renewed growth till L has been reached, when at that position a third terminal spore has been formed. These terminal bodies, H, H, H, perform the part of seeds, and reproduce the species, though they are not real seeds, or even spores in the true sense of the term

* "Science for All," Vol. I., p. 19.

Sometimes one will burst and grow whilst it is still on the mother stem, as at M; at another time a fallen piece of the fungus, as at N, will burst at the side, and rapidly form a new plant.

Till within the last five years, and during the previous thirty years, an impenetrable mystery had hung over the fungus of the potato disease, in fact ever since the fungus had been known and examined by competent botanists. The deep mystery related to its sudden appearance and its equally sudden disappearance. It generally came suddenly in July, and then increased and multiplied with such extraordinary rapidity that in a few days it would cover the whole of North-Western Europe, but in September the fungus vanished as mysteriously and suddenly as it came, and no one knew whence it had come or whither it had gone. It was strongly suspected that the fungus existed in some other form, in a larval, chrysalis, or resting-seed form; but the detection of any such secondary condition of the fungus defied all the eyes and all the microscopes in the world. Botanists everywhere were incessantly looking for a secondary state of the fungus, and the result was invariably *nil.* One person only, a French botanist named Montagne, once saw some mysterious bodies in decayed potatoes which he could not understand. These minute organisms he transferred to the admirable English botanist who is still amongst us—the Rev. M. J. Berkeley—and this latter gentleman at once published his belief that the bodies, imperfect as they were, and unattached to the potato fungus proper, were no other than the hibernating germs of the fungus of the potato murrain. From lack of sufficient material, Mr. Berkeley was unable to give any actual proofs of the correctness of his ideas, but from his first printed opinion he never departed. Mr. Berkeley fortunately preserved the specimens between pieces of talc, but no other person could ever again light on the mysterious bodies once found by Dr. Montagne. Now, the year 1875 was a terrible year for the potato disease; instead of appearing in July, it was upon us in May. Horticulturists bewailed the advent of a "new disease" of potatoes, and specimens of the "new disease" were sent to the writer of these lines for examination. The "new disease" proved to be the old disease in disguise, and whilst the writer of this notice was one night examining and re-examining the early and abnormal development of *Peronospora infestans,* some of the round bodies, as originally seen by Dr. Montagne, were suddenly displayed before his eyes

on the field of the microscope; they were not outside the potato leaf, but within the tissues, and they appeared as at P, P, P, Fig. 1. Many of the small bodies had a still smaller one attached to them, as seen in the diagram. They might have been easily overlooked, as they were transparent, and exactly the same in size with the constituent cells of the leaf, as seen at Q, Q, Q.

But 150 diameters is insufficient to show the

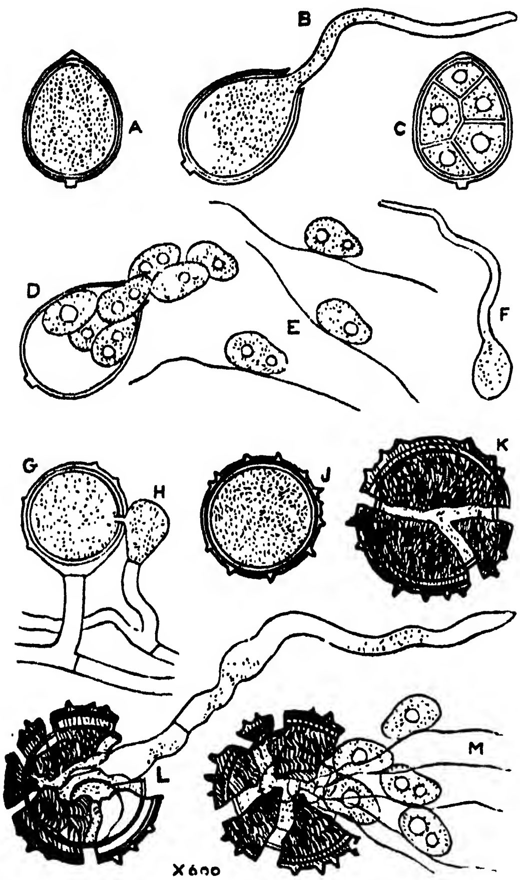


Fig. 2.—Essential Parts of the Fungus of the Potato Murrain. (Enlarged 600 diameters.)

nature of the more minute portions of the potato fungus; so in Fig. 2 all the essential parts of the fungus are further enlarged to 600 diameters; one of the apical conidia, or non-sexual cells, equivalent to a spore or seed, is shown at A. This organism has a very short existence; it grows by throwing out a tube or thread, as at B; this thread is the beginning of a new plant, and should the germination take place upon a potato leaf, the protruded thread will pierce the leaf, and force its way amongst the leaf-cells, and soon corrode and discolour every part of the leaf. This fact of cell-corrosion and blotching from contact is one proof that the fungus is capable of *causing* the disease. Sometimes, however, the conidium does not burst at once, but a process of differentiation goes on inside the seed-like body, reminding one of crystallisation, although crystallisation is really a widely different phenomenon; the interior mass becomes divided into from three to eight or more nucleated portions, as shown at C. Ultimately the conidium bursts, and now discharges these portions as irregularly oval bodies, D. These latter small organisms soon perish, unless they fall on a suitable matrix. If moisture is applied to them they quickly develop two lash-like tails or flagellæ, as at E, and sail quickly about in all directions. When they fall on a potato leaf, they enter the stomata or mouths, and burst or germinate within the leaf, corroding all the parts they touch. At length these small bodies, named zoospores—because they look like living seeds—go to rest, burst and throw out a thread or tube, as at F. Should the bursting of a zoospore (which has rested) take place upon a potato leaf, the protruded thread penetrates and corrodes the leaf at once, and the tiny tube is the beginning of another new corrosive plant of the potato fungus. One spray of the fungus is capable of producing a thousand of these zoospores, and as there are hundreds of thousands, or millions, of mouths from which these sprays emerge on every potato plant, there are, as a consequence, thousands of millions of zoospores produced on every infected plant. A field of potatoes therefore, on a wet day, with the damp leaves flapping together, is like an almost illimitable sea, full of reproductive bodies, these bodies being on the plants, on the ground, and sailing through the air.

The above facts have been more or less surmised or known for the last thirty years. Mr. Berkeley made the original observations on which all after-work has been grounded. The knowledge of the fact of the zoospores being motile in water, and furnished with lash-like tails, is due to Professor De Bary, of Strasbourg.

It is now time to revert to the minute bodies first seen in the tissues of diseased potatoes by Dr. Montagne, and then by the writer of this essay. One of the first things done by the writer was to compare the new with the old specimens. This was satisfactorily done, and the two sets of specimens were found to be identical, with the exception that Dr. Montagne's bodies were furnished with a few minute projections or spines, which

in the process of growth the newly-found individuals very quickly produced, so that the two sets of bodies were acknowledged to be the same in every way. Both series of examples are preserved for examination.

These intercellular organisms are, as was at first correctly surmised by the Rev. M. J. Berkeley, resting-spores, or bodies whose office is to continue the existence of the parent plant in a state of rest or hibernation for a long period of time. When that period comes to an end the resting-spores burst and grow, and produce new conidia; these seed-like conidia get blown by the wind everywhere, and such as fall on to healthy potato plants infect them at once with the murrain. One plant then rapidly infects another, so that from only a few centres the disease may cover one-quarter of the world in a few days. How this state of things comes about, and how the additional knowledge which accounts for the sudden appearance and disappearance of the potato fungus was acquired, will now be explained.

At G, Fig. 2, is shown one of these resting-spores in an early condition. Montagne merely observed the larger of the two bodies, one of which is here seen in contact with a smaller one; the larger one is the egg, the oogonium or female; but in the 1875 specimens, the second body—the antheridium, or male organism—was abundant. The oogonium can reproduce the potato disease without the presence of the antheridium; but to produce a true zoospore, resting-spore, fertile seed, or impregnated egg of the potato murrain, the antheridium must come in contact with the oogonium, as seen at G, H. At the time of contact the antheridium H thrusts a minute beak into the wall of the oogonium, and the contents of the former pass through the beak and mingle with those of the latter; the antheridium now perishes, and the beak is left in the side of the oogonium. When these curious observations were first published by the writer, although they accorded with what was known of allied plants, the statements were challenged in nearly every quarter, especially in Germany. The resting-spores were said to belong to any plant but the fungus of the potato disease; some Professors said one thing, other Professors said another, and no one Professor agreed with his fellow. The Royal Horticultural Society of England, however, expressed the decided opinion of its Council, by awarding the writer of this article the Knightian Gold Medal of the Society.

No secret was made of the details of the discovery, as full particulars were published of how the production of the resting-spores might be accelerated under a certain cultural treatment of the infected potato plant. The instructions were followed by several English botanists; some of these raised a crop of resting-spores, whilst others, less fortunate, got nothing.

The possessors of the spores were now in a great difficulty, for they were entirely in the dark as to the proper mode of treatment. No one knew whether the spores ought to be kept dry in the air, or wet in water, or whether they would rest for a week or for a year or for an indefinite number of years. Meantime the dispute as to their nature was raging in a disagreeable manner both on the Continent and in England. No amount of raging, however, would make the spores germinate, or make them show any signs of life; in fact, it was not quite certain whether the resting-spores were alive or dead. At length the Great Hereford Fungus Meeting took place, in October, 1875. Here a small phial of water was produced, in which resting-spores had been bottled and sealed up since the previous May. With breathless anxiety a microscope was set in order, the bottle opened, a test-tube inserted, and a drop of the water placed under the microscope. To the joy of all present, the resting-spores appeared to be alive and well; they had grown somewhat in size, as at J, Fig. 2, had produced a few more spines, and were now pale brown in colour, instead of transparent, as at first. The phial of water with the spores was again sealed up, and the contents kept for future observation.

The decayed potato material containing the resting-spores was kept for a whole year, mostly in water or moist air. To keep such very minute organisms as the resting-spores alive, and free from the attacks of enemies, animal and vegetable, for an entire year, was a matter of the utmost difficulty. Innumerable preparations had to be made, and these preparations watched almost night and day with the microscope for one year. At length, after the weary year had elapsed, the resting-spores (now distributed over various parts of Great Britain) simultaneously showed signs of renewed life. From being transparent, as they were at first, they had become deep brown in colour; and they had also increased in size, and begun to crack their outer coats, as at K, Fig. 2. The anxiously-waited-for end of the tedious observations was now at hand; some of the resting-spores burst, as at L, and protruded a long tube or thread. This, on being placed on

fresh potatoes, at once corroded the tissues and reproduced the fungus of the potato disease. Other of the resting-spores burst, as at M, and instead of protruding a tube, they discharged a number of zoospores, which sailed out from the inside of the spores like so many swimming seeds. These latter bodies speedily came to rest, burst, threw out a thread, and in turn produced the fungus of the potato disease, corroding the leaves of the potato and frequently blackening the starch of the tuber.

The above observations were confirmed by several English observers in different parts of the country. They prove that the potato fungus of one summer produces hibernating germs which remain in a quiescent condition till the summer of the succeeding year. These resting-germs, formed from buds from the intercellular threads of the potato fungus, fall to the ground with the decayed potato plant. They exist in every part of the diseased potato plant—leaves, stems, and tuber. The resting-spores remain on or in the ground, and thrive best in rank, wet places; in these places they remain, and continue to ripen themselves for a year. The humid, hot weather of summer is the time for their reawakening to life, and then they grow, and produce conidia upon the place where they have rested. The air rapidly carries these seed-like conidia in different directions, and a new onslaught of the murrain for a few weeks is the result. No doubt innumerable resting-spores perish during the winter, as do the eggs of insects; but the egg condition of the fungus is a manifest state of protection against the droughts, floods, and frosts of winter.

It is curious that, although the resting-spores were sent to various parts of England, they all burst at about the same time.

Very little has been done with the fungus of the potato disease since 1876, and the reason is obvious. For any private person to repeat the above-recorded observations, he must give up the best part of his time for an entire year; and if the slightest hitch occurs with any of the preparations—if any get too wet or too dry, or mites or moulds appear—the whole of the observer's time will have been lost.

Nothing is easier than the destruction of the fungus. Many simple chemical preparations collapse and destroy it instantly and utterly; but the difficulty, though it may not be an insuperable one, rests in the application and contact. It is easy to destroy laboratory specimens, but when it comes to a field of a hundred acres, the case is very different.

No account of the fungus of the potato disease can be considered complete without a reference to a second fungus found upon the potato. Its name is *Fusisporium solani.* It almost invariably accompanies the potato fungus proper, *Peronospora infestans;* it appears and reappears with equal suddenness, and it is almost as destructive. *Peronospora* is the lion, and *Fusisporium* is the ever-present jackal. If the *Peronospora* by chance leaves any potatoes unscathed, the *Fusisporium* is certain to make its attack, and destroy every particle that may be left.

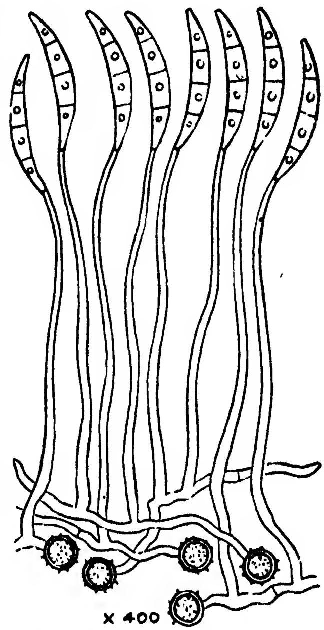


Fig. 3.—The Fungus (*Fusisporium solani*) second in order of the Potato Murrain. (Enlarged 400 diameters.)

The *Fusisporium* grows upon the leaves, stems, and tubers of potatoes. Its appearance to the naked eye is not to be distinguished from the *Peronospora.* It looks like a fine white bloom, and it grows in dense masses. Under the microscope it looks like a thickly-planted corn-field, all the stems and heads of corn being transparent like glass. The heads break to pieces, each piece acting the part of a spore or seed; and the spores are carried through the air by the wind, and wherever they fall upon potatoes they blight and destroy them.

In Fig. 3 is shown this latter fungus (enlarged 400 diameters) arising from its resting-spores—bodies discovered by the writer of this article.

To persons unfamiliar with the life-history of minute fungi the foregoing explanations may at first seem a little involved, but to those who know the habits of a large number of small vegetable parasites, the facts just enumerated are of the simplest and easiest character. The phenomena mentioned follow each other with unerring exactness, and the life-processes of different parasites, when once fully known, appear never to depart from well-marked courses.

We learn, then, from a searching examination of a diseased potato with its accompanying mildew, or

mildews, that the potato is highly susceptible to the attacks of two minute parasites. So potent for evil are these parasites that they produce immediate disorganisation of the tissues of the potato by simple contact; so small are the parasites in size that they require the highest powers of the microscope to see all their parts, and so tenacious of life as to be capable of carrying on existence for one (or several) years in a hibernating condition in the ground or in water. The reproductive power of the potato fungus proper is almost unparalleled; the seed-like bodies it produces are innumerable, and all these bodies are again capable of increasing themselves tenfold: added to this, any detached atom of the parasite is able to continue growth and rapidly make a new and perfect individual, this individual being the predestined mother of a limitless family. When rains or drought destroy every vestige of the potato fungus, as we commonly know it in an active state, then it quietly rests in the ground for a year or more in a sleeping or hibernating condition. It is in the meantime protected by a thin, hard shell, which defends the living germ within from wet, drought, and frost. The resting-spores are in the ground everywhere, their numbers are countless, their size so small as to be invisible without a microscope for their detection.

EMERALDS AND BERYLS.

By F. W. Rudler, F.G.S.

Curator of the Museum of Practical Geology, London.

It is related by the elder Pliny, who wrote his famous "Natural History" eighteen centuries ago, that in olden times, when the Isle of Cyprus was not only "a place of arms," but a place of trade, there stood on the shore of the island, overlooking the tunny-fishery, a noble figure of a lion keeping watch and ward over the tomb of King Hermias. This figure was sculptured in white marble, and the eyes of the creature were represented by two huge *emeralds*. But the lion had not long been mounted upon its pedestal before the fishermen who dwelt on the coast complained that the brilliant rays shed forth from this green-eyed monster penetrated the neighbouring waters, and scared the fish from their accustomed haunts. On this plea, the cunning fellows plucked the gems from their marble sockets, and thereupon the fish returned to their wonted waters, and the fishermen resumed their lawful craft.

This story of Pliny's is worth repeating at the present day, because it teaches us one or other of two things. Either the emerald must have been a much more abundant stone with the ancients than it is with us, or, what is far more probable, the ancients must have applied the term to stones of a very different kind from those which are recognised as such at the present day. The truth is that, before mineralogy became a science, men were forced, when they attempted to name a stone, to rely upon the most superficial and trivial of characters. Colour is, of all physical characteristics, the most striking; and it was colour, consequently, that guided the older mineralogists in most of their feeble gropings after a rational system of classification.

In the case of the emerald—the *Smaragdos* of the Greeks—it is almost certain, from the accounts of ancient writers, that a number of minerals must have been confounded together, having little or nothing in common except a green colour. Some of the ancient emeralds may, indeed, have been the true emerald of the modern mineralogist, but others were nothing but comparatively worthless copper-ores. The emerald of Cyprus, for example, was probably unlike our modern emerald in every respect save colour. Carefully as the island has been searched, no true emerald has been found there in modern times. Copper ores, on the contrary, are known to occur in the island, and were worked at so early a period that the Latin word for copper, *cuprum*, is said to have been derived from the Greek name of the island, *Kupros*. Now, in connection with copper deposits, we not unfrequently find a number of greenish minerals, such as the well-known malachite, which is a carbonate of that metal. It is therefore highly probable that the famous Cyprian emerald—the stone that got into such ill repute with the tunny-fishermen—was nothing but a copper-bearing mineral of bright green hue. Other so-called emeralds may have been green jasper, while others again were, in all likelihood, simply pieces of green glass, turned

out, it may well have been, from the ancient glass-houses of Alexandria.

Whatever elasticity may formerly have been permitted in the use of the term emerald, or its classical equivalents, it has acquired among modern mineralogists a very definite and scientific meaning. The term is, in fact, restricted to the green varieties of a particular species of matter, which possesses a well-determined chemical constitution and a fixed set of physical properties. To ascertain its composition, a gem has occasionally been sacrificed in the interest of science. The chemist, after ruthlessly destroying the beautiful stone, has reported that it contains a large proportion of *silica*, a substance which occurs in its purest form as rock-crystal, and which takes its name from the fact that it constitutes the material of flint or *silex*. The emerald is, in fact, a compound containing silica, and is known in the language of chemistry as a *silicate*. But since the silica forms less than seventy per cent. of the entire gem, it remains to determine what are its other constituents.

On exposing the emerald to further tortures in the laboratory, the chemist has been able to obtain from it a certain proportion of *aluminium*—that silvery metal which was described in the article on rubies and sapphires (Vol. II., p. 362). We may infer that, since the emerald contains silica and aluminium, it is therefore a *silicate of aluminium*. It is this; but it is much more than this. The chemist, by increasing the subtlety of his researches, has been able to extract from the emerald another metal, far more rare than aluminium, known as *glucinum*.

This metal is found only in some half-dozen other minerals, and is not often extracted even from them. In fact, the raw materials from which glucinum may be procured are so expensive, while the process of extraction is so tedious and delicate, that many a chemist who spends his days in the laboratory has never set eyes upon a specimen of the metal.

The name glucinum has been given to this rare metal because it yields a series of salts, which are characterised by possessing a *sweetish* taste. We may remind the reader that from the Greek word *glukus*, meaning "sweet," we obtain, not only the name of this metal *glucinum*, but also the name of the better-known body, glycerine; while the same word, in a disguised form, appears in the familiar liquorice, which is merely a corruption of *glycyrrhiza*, or the "sweet root."

Since the emerald contains two metals, or bases, combined with silica, it is in chemical language a "double" silicate—a silicate of aluminium and glucinum. It is, therefore, the most complex mineral which we have yet studied in these papers on gems. When the diamond was examined, it was found to consist of carbon only, and it is therefore a chemical *element* (Vol II., p. 194). When the ruby and sapphire were studied, they were found to consist of alumina, and they are therefore chemically *oxides* (Vol. II., p. 363); but the emerald, being a double silicate of aluminium and glucinum, is technically placed in the group of *salts*. The diamond contains but *one* element, carbon; the ruby contains *two* elements, aluminium and oxygen; while the emerald contains no fewer than *four* elements, aluminium and glucinum, silicon and oxygen; for silica itself is the oxide of a body called *silicon*.

By some chemists, especially in Germany, the metal glucinum is termed *beryllium*, a name which it has acquired from the fact that it exists not only in the emerald, but also in the beryl. Indeed the beryl, when pure, has exactly the same composition as the emerald, and the two stones are therefore classed together by mineralogists as one and the same species. The term emerald is restricted to the bright green transparent crystals, while the term beryl is reserved for those forms which are coarser in structure and paler in tint. But just as it was seen in a former article that the ruby and sapphire, however different to the eye, belong really to a single species, so the emerald and the beryl, notwithstanding their differences, are united in a single mineralogical species.

Since emerald and beryl form but one mineral species, it may fairly be supposed, according to principles already laid down,* that they possess the same characters of crystallisation. And such a supposition is perfectly correct. Both minerals, in fact, crystallise in forms which possess a six-sided symmetry; and they are therefore akin in crystallisation to the ruby and sapphire. But while ruby and sapphire crystallise in double six-sided pyramids, the emerald and beryl crystallise in six-sided prisms. Figs. 1 and 2 serve to show at once the similarity and the difference in the two cases; the similarity is seen in the six-sidedness, common to the two crystals; while the difference is visible in the fact that the emerald-crystal has six side-faces, and is flat at top and bottom, whereas the sapphire-crystal has a dozen triangular faces, and tapers to a point at each extremity.

* "Science for All," Vol. II., p. 366.

It must not be supposed that the emerald invariably assumes so simple a form as that indicated in Fig. 1. Frequently the crystal becomes complicated by a multitude of additional faces, which

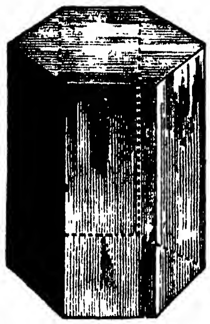


Fig. 1.—Typical Crystal of Emerald.

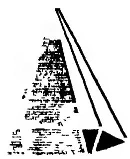


Fig. 2.—Typical Crystal of Sapphire.

run round its edges and cluster around its corners, as represented, for example, in Fig. 3. But however complex the crystal, and whatever may be the number of faces which it carries, it never swerves from its proper symmetry. Notwithstanding the complexity of its modifications, it still remains true to the crystallographic group of which it is a member, and all its vagaries are kept within the limits of the laws which rule in the hexagonal system.

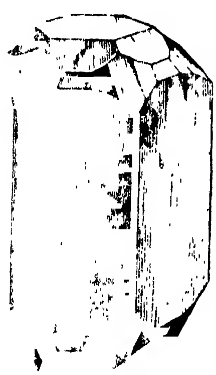


Fig. 3.– Complex Crystal of Emerald, rich in faces.

In crystals of beryl it often happens that the six sides of the prism, instead of being perfectly smooth, are roughened by a number of channels or furrows running lengthwise down the crystal. These irregularities of surface are called *striations* and are represented in Fig. 4. Such grooves are in some cases so deep and so numerous as to obliterate the edges, and thus to transform the prism almost into a cylinder. It should be noted that such striations occasionally aid the mineralogist in separating one mineral from another. Quartz, for example, is a substance which, like beryl, assumes six-sided prismatic forms, and moreover these prisms are also striated, but then the striations in this case run *across* the prism, as represented in Fig. 5. If a mineralogist were blind-folded, and had a crystal of beryl in one hand, and a crystal of quartz in the other, he could easily distinguish between them, solely by the sense of touch; he would feel at once that the striations on the prism of beryl were longitudinal, while those on the rock-crystal were transverse. Compare Fig. 4 with Fig. 5. It will thus be seen that apparently the most trivial character, if constant, is not to be despised as a means of mineralogical discrimination.

Again, if a crystal of beryl and a crystal of quartz be broken by a fall on to the floor, or by a blow with a hammer, a marked difference in the nature of the fracture will at once be observed. The beryl or emerald breaks with ease *across* the prism, yielding fragments which have smooth and brilliant faces: they are, in fact, cleavage-planes, such as were mentioned when describing the diamond;* but the quartz commonly breaks without the slightest trace of cleavage; that is to say, the fracture is irregular, and the fragments do not present flat faces. It breaks, in fact, just as a piece of

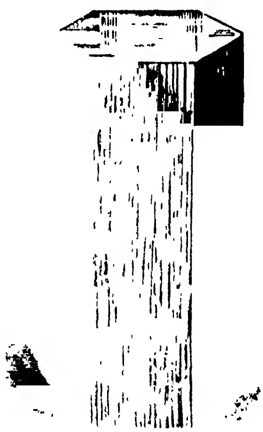


Fig. 4.—Crystal of Beryl, showing longitudinal striations.

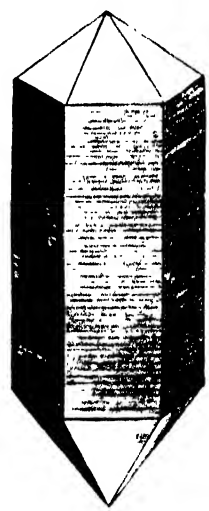


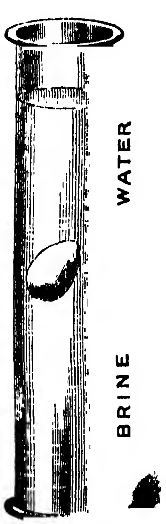
Fig. 5.– Crystal of Quartz, showing transverse striations.

common glass would break. Many emeralds belonging to Oriental potentates are mounted in the form of cleaved slices, which are nothing but broad flat pieces split from the stone, and having faces so smooth as to need no touch of the lapidary to heighten their lustre.

Another useful characteristic of beryl, or emerald, serving to distinguish it not only from quartz, but from several other substances with which it might be confounded, is to be found in the specific gravity of the stone. The specific gravity of the

* "Science for All," Vol. II., p. 191.

beryl is about 2·7; in other words, it is rather more than two and a half times as heavy as an equal bulk of water. In the article on the ruby and sapphire, the ordinary method of determining the specific gravity of a gem, by means of the so-called hydrostatic balance, was fully described. There is, however, another method which is at once simple and rapid, and can be used with advantage in examining certain precious stones, such as the emerald. Before describing this method, it is necessary to explain the principle upon which it is based.



ig. 6.—Experiment to illust differ- ence bet ... Den- of Brine and of ...er.

When a country housewife wishes to know whether a tub of brine is strong enough for pickling, she sometimes places an egg in the liquid, and observes whether it floats or sinks. Let an egg be dropped into a glass of common water, and it immediately sinks; but place it in concentrated brine, and it readily floats. There is an amusing experiment which is sometimes introduced into popular lectures to illustrate this difference. A tall glass cylinder is half filled with brine, and then very gently filled up with ordinary water. The water floats upon the dense brine, and since both liquids are colourless the junction is not detected by the eye. When the lecturer drops an egg into the cylinder, it immediately falls through the water; but on reaching the surface of the brine it stops, as if by magic, and remains suspended in the middle of the vessel, just as Mohammed's coffin is said to be poised in mid-air. The experiment is illustrated by Fig. 6.

When a body is immersed in a liquid, it of course displaces, or pushes aside, its own bulk of the liquid. If the weight of this displaced liquid be greater than the weight of the body, the latter floats; but if the weight of liquid be less than the weight of the body, the latter sinks; while if the weight of the liquid be equal to that of the body, the latter will neither sink nor swim, but will remain suspended indifferently in any part of the liquid. In the experiment just described, the egg sinks through the layer of water, because the weight of the egg is greater than the weight of a volume of water exactly the size of the egg; but it floats on the brine, because its weight is less than the weight of an equal bulk of brine. In other words, a solid body floats or sinks in a liquid according as its "specific gravity" is less or greater than that of the liquid; while if the solid and the liquid be of equal density, there is no tendency either to sink or to float.

If, now, an emerald be dropped into a glass of water, it will of course immediately sink, for the specific gravity of the stone is 2·7, while the specific gravity of the water itself is only 1, pure water being the standard of density, and therefore represented by unity. But it is evident that if we could obtain a liquid having a specific gravity higher than 2·7, then the emerald would float upon this liquid just as an iceberg floats in sea-water, or as a leaden bullet floats upon quicksilver, or as the egg floats upon the brine in the experiment cited above. It is by no means easy, however, to obtain suitable liquids of sufficiently high density; but some years ago Mr. E. Sonstadt drew attention to a liquid which admirably fulfils the necessary conditions.

There is a chemical compound known as *mercuric iodide*, which presents so beautiful a colour that it has occasionally been used as a scarlet pigment. This body is not soluble in water, but it dissolves freely in a solution of iodide of potassium, and the resulting solution when concentrated has a specific gravity as high as 3, or even a trifle higher; in other words, a wine-glass of this solution weighs three times as much as the same glass of water.* Professor Church, who has made the subject of precious stones a specialty, suggested some years ago that this solution might be used with advantage by the mineralogist in his examination of gems. For example, an emerald having a specific gravity of 2·7 would float on "Sonstadt's solution," as Professor Church has conveniently termed it; but a green sapphire—the stone which is known to mineralogists as *Oriental emerald*—will sink, since its specific gravity is about 4. Here, then, is a simple method of discriminating between the two gems. No balance is needed; all that is necessary is to have a small bottle or glass of this dense liquid, and, on dropping the suspected stone into the vessel, we tell in a moment whether it is a green sapphire or a true emerald. In like manner, we could distinguish an emerald from a green garnet, the latter sinking while the former

* It is not necessary here to enter into the exact details of preparing this solution, but it should be expressly stated that the liquid is *extremely poisonous*.

floats. This method of testing a suspected gem almost reminds one of the old rough-and-ready way of determining whether a suspected individual were a witch or not, by throwing her into a horse-pond, and observing if the unfortunate creature swam or sank.

Sonstadt's solution may also be used with advantage, as Professor Church has well pointed out, to distinguish a colourless beryl from a piece of rock-crystal. Some beryls are so pale as to look like crystal; but if Sonstadt's solution be diluted to a specific gravity of 2·67, it affords a ready means of sorting beryls from crystal. Beryl has a specific gravity of about 2·7, and therefore sinks in this diluted liquid; while the crystal, having a density which never exceeds 2·65, must needs float. Here it is interesting to note the extraordinary delicacy of Church's test, for the difference in the density of the two stones does not exceed ·05, and yet the solution is available for detecting this trifling difference.

It should be noted that if an emerald, instead of a beryl, be dropped into the solution having a density of 2·68, the observer cannot be certain that the stone will sink; for the emerald is almost invariably flawed, and is sometimes so full of cracks that the enclosed air lessens the density of the stone to such an extent that it becomes as low as that of rock-crystal. There is little fear, however, of the brilliantly-coloured gem, emerald, ever being confounded with rock-crystal. It is worth noting, however, that the presence of flaws in this stone is so general that the expression, "An emerald without a flaw," has passed into a proverb. When this gem is imitated in paste, the artificer frequently introduces the characteristic flaws to entrap the purchaser. If a counterfeit emerald, entirely free from flaws, were presented to a purchaser, it would really be too good to be real, and its very perfection would immediately arouse suspicion.

Next to specific gravity, the *hardness* of a mineral generally demands attention. Hardness is a character which is naturally prized in precious stones, inasmuch as it enables them to resist the effect of wear, and preserves their lustre of face and sharpness of edge. The emerald, however, is far inferior in hardness to the gems which have previously been described in these articles. Thus, while the hardness of the diamond is indicated by 10, and that of the ruby by 9, on the scale referred to at p. 364, Vol. II., the emerald scarcely reaches the eighth degree of this scale. It is scratched by a topaz, but is slightly harder than rock-crystal. When Pliny says that certain emeralds are too hard to be engraved on, it is clear that he cannot be referring to the stone which we call emerald. What he really meant was, in all probability, the green sapphire, which is still known to mineralogists as *Oriental emerald*.

Those physical characters which we have already discussed—crystallisation, density and hardness—are utterly unimportant in the emerald, when compared with the *colour* of the gem. It is its peculiarly vivid green hue that has rendered the stone in all ages a popular favourite, and which compensates for such imperfections as inferior hardness and the presence of flaws. Every one knows that the fatigued eye rests with relief upon any green object, and hence old writers like Theophrastus and Pliny extol the virtues of the emerald as a cure for weak eyesight. Dr. Holland, in his quaint translation of Pliny, published in 1601, tells us that "if the sight hath beene wearied and dimmed by intentive poring upon anything else, the beholding of this stone doth refresh and restore it againe."

Occasionally the emerald was cut with a curved face, and used by the ancients as a lens, or, as Pliny says, "shaped hollow, thereby to gather, unite, and fortifie the spirits that maintaine our eyesight." Nero is said to have used an emerald lens, through which he viewed the gladiatorial combats in the circus. As the emperor was short-sighted he found the benefit of a concave lens, while the colour of the emerald would give ease to the tyrant's eyes when wearied with the brutal sight. The value of green media led to the use of green spectacles in modern times; and every one must remember how Moses, in the "Vicar of Wakefield," made a sorry bargain when he bought them by the gross. Not only the vivid emerald, but the paler beryl, has been used to assist the sight, and it is likely that the German word for spectacles, *Brille*, is connected with *beryl*. The Rev. C. W. King, a high authority on gems, has pointed out that the low Latin word *beryllus* signifies a magnifying glass.

When the colour of an emerald is not a bright but only a pale green, the stone is termed an *aquamarine*, since the tint is compared to that of clear sea-water. An aquamarine of pale colour may easily be mistaken for a topaz, some varieties of this gem having a very similar tint; but an appeal to Sonstadt's test-solution at once sets any doubt at rest. If the solution have a density of 3, an aquamarine will float upon it, while a topaz will sink, since its specific gravity rises to about 3·5.

The aquamarine is sometimes cut and polished for the purposes of the jeweller, but the stone is not highly valued. It has also been used, especially in the East, for the handles of swords and daggers. Fig. 7 represents a matchless aquamarine

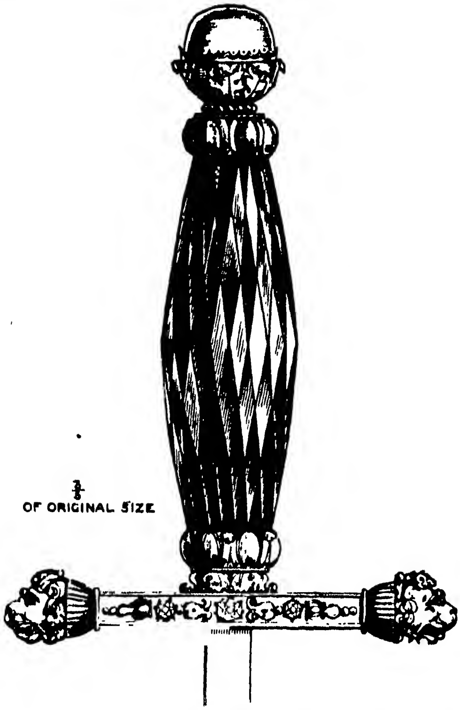


Fig. 7.—Aquamarine, mounted as sword-handle: in Mr. Beresford-Hope's collection. (*From the Hertz Catalogue.*)

in the collection of Mr. Beresford-Hope, now exhibited at the South Kensington Museum. This aquamarine, which was at one time in the handle of King Joachim Murat's sword, measures four inches in length, and weighs three and a half ounces.

In colour a typical aquamarine is singularly like the greenish glass used for soda-water bottles, and many a seaside lapidary could tell curious tales arising from this resemblance. It has not unfrequently happened that a lady in quest of pebbles on the beach has had the good luck to find what she regards as a fine specimen of aquamarine, and has spared no expense in having it cut, polished, and elegantly mounted for personal decoration. Of course no lapidary could have the heart to tell the good lady that her treasure was nothing but a water-worn fragment of the thick bottom of a soda-water bottle cast away by some excursionist of the previous season.

It often happens that the natural crystals of the double silicate of alumina and glucina possess neither the vivid green of the true emerald nor the delicate hue of the aquamarine, and it is then that they pass under the name of *beryl*. The beryl may vary considerably in colour, presenting any shade of blue or green, yellow or brown, or it may even be colourless. Again, it may be either perfectly clear or perfectly opaque, or it may present any intermediate degree of translucency. But whatever its colour, and whatever its translucency, the stone is still the same thing to the mineralogist. In crystalline form, and in chemical composition, the emerald, the aquamarine, and the beryl are one and the same stone; they are, in short, but so many varieties of a single species of matter. There are wide differences, however, in their respective values, for while the true emeralds are highly prized, and even the aquamarine is held in some esteem, the coarser forms of dull-tinted beryl are utterly valueless to the jeweller.

Since the emerald is prized mainly on account of its vivid green colour, it becomes interesting to inquire into the origin of this tint. In many cases it is extremely difficult to determine the precise nature of the colouring matter present in a gem, for the tinctorial power of some mineral-pigments is so intense that the veriest trace may suffice to produce a decided tint, and this trace may elude detection by the chemist, unless his methods are extremely searching. The old mineralogist, Klaproth, supposed that the green colour of emerald was due to some compound of iron, and although he was wrong in this supposition, it is yet certain that the dull colours of some beryls are traceable to the iron which they contain as an impurity. When the French chemist Vauquelin first determined the composition of emerald in 1797, he found that the mineral contained chromic oxide. Now, it is well known to chemists that this oxide is capable of imparting a fine green colour to glass: it is used, indeed, as a green pigment in painting on pottery, and in enamelling. What, then, more natural than to assume that the colour-giving property of this oxide comes into play in the emerald, and that this gem owes its beauty of hue to the chromic oxide which it contains?

Such an assumption had taken firm root among mineralogists for many years, when a blow was levelled at it by M. Lewy, who in 1848 visited the great emerald mine of Muzo, in Colombia. On his return to France, he examined the composition of some of the specimens which he had brought home, and found in them only such minute traces of chromium, that he believed the

quantity to be utterly insufficient to produce the intense greenness of the emerald. More than this; he affirmed that when the emerald is strongly heated it loses its colour. Now, chromic oxide, the reputed colouring matter of the emerald, is a very stable pigment, and ought not to be materially affected by heat. It is, in fact, used in potteries as one of the few "under-glaze colours;" that is to say, colours which can be painted on the "biscuit" before glazing, since it is not affected by the heat to which the ware is afterwards exposed in the gloss-kiln.

Admitting that the colour of the emerald is fugitive, and is therefore not due to the presence of chromium, we have a right to ask M. Lewy how he explains the origin of the green tint. On igniting an emerald in oxygen, he found that carbonic acid gas was produced, just as is the case when a diamond is burnt under similar conditions. This experiment shows, therefore, that the emerald must contain carbon. Moreover, M. Lewy found that the emerald, when ignited, lost weight, and that while part of this loss was due to the escape of water, he inferred that part also was due to the expulsion of some hydrocarbon, or compound of carbon and hydrogen of organic origin. The emeralds of Muzo are found in a black bituminous limestone containing ammonites and other fossils, which appear to indicate that the rock belongs to that set of strata which geologists call the *Neocomian* beds. It would, therefore, not be unreasonable to conjecture that the decomposition of the animal matter which these fossils represent might readily yield the hydrocarbon which Lewy is said to have obtained, and to which he attributed the colour of the emerald.

There is no difficulty in believing that an organic hydrocarbon may act as an intense green pigment. Indeed, Lewy compared the colouring matter of the emerald to the green colouring matter which is so abundantly distributed through the vegetable world. Every green leaf owes its tint to the presence of the organic substance called *chlorophyll* (Vol. I., pp. 21, 24, 295, 300, 376, 378). If the colouring matter of the emerald be akin to chlorophyll, as M. Lewy suggested, what an unexpected relation is established between the mineral and the vegetable kingdoms! Gems have often been fancifully called the flowers of the mineral world; but if the green emerald and the green leaf are tinted by similar substances, there may, after all, be more truth in this conceit than was ever dreamt of by the poet.

Interesting as M. Lewy's inquiries unquestionably were, it must be admitted that his conclusions have not stood the test of time. Dr. Greville Williams in this country, and Hofmeister, Wöhler, Gustav Rose, and Boussingault on the Continent, have all given attention to this difficult question, and in no case have Lewy's conclusions been corroborated. Thus Dr. Williams finds that the Muzo emerald does not become bleached when exposed for several hours to a red heat, and it is only after prolonged heating in a fused state that it begins to grow pale. Surely no organic colouring matter could maintain its integrity after some hours' exposure to a glowing heat, and nothing related to chlorophyll could possibly stand such severe treatment. Nevertheless, it is placed beyond doubt that the emerald does contain small quantities of carbon, as stated by Lewy. Dr. Williams, however, has found just as much carbon in a colourless beryl as in the richest-tinted emerald; and it is therefore impossible to connect the presence of this element with the colour of the gem, as M. Lewy had attempted. In fact, Dr. Williams rather inclines to the notion that the carbon exists in a free state, perhaps as microscopic particles of diamond disseminated through the substance of the emerald.

On the whole, it seems clear that no organic colouring matter is present in this gem, and that the balance of evidence on this vexed question tends to show that chromic oxide is the true green pigment. Vauquelin, the discoverer of chromium, was therefore, after all, correct in the speculations which he put forth eighty years ago, when he first detected the presence of his new metal in the emerald.

While referring to the colour of the emerald, it will be instructive to explain a phenomenon which is exhibited by this mineral, in common with several other coloured gems. This is the phenomenon of *Pleochroism*, or many-colouredness. Certain minerals are found to display differences of tint according to the direction in which they are viewed. There is one mineral which so conspicuously exhibits two colours that it has earned for itself the name of *Dichroite*, or the double-coloured stone. In like manner the emerald is dichroic, or double-tinted, but its dichroism is not in general sufficiently strong to be observed without the aid of a special instrument. Such an instrument was devised many years ago by Professor Haidinger, of Vienna, and is known as the *Dichroiscope*. It is a neat little instrument, which, as ordinarily constructed, shows externally nothing more than a brass tube about six inches in length, carrying at

one end an eye-piece, and at the other end a perforated disc. Its form is shown in Fig. 8.

In order to explain the construction of this instrument, we may suppose the outer case split

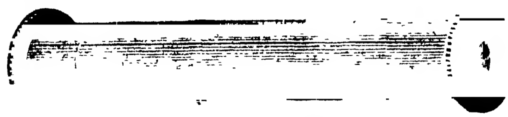


Fig. 8.—The Dichroiscope.

open lengthwise so as to display its interior, as in Fig. 9. We then see that the body of the tube is chiefly occupied by a long piece of Iceland spar (A).* This is, in fact, a cleaved rhombohedral fragment of spar, which has had its two ends ground flat, at right angles to the axis of the tube.

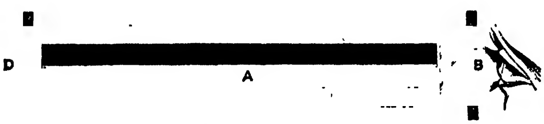


Fig. 9.—Internal Construction of Dichroiscope.

In some instruments the ends are not ground in this way, but two little wedges of glass are cemented on to the ends. Close to the round hole (B) through which the eye looks into the instrument is a convex lens (C), while at the other end (D) the instrument is closed by a metal plate having a small square aperture pierced in the centre. Suppose for a moment that the calc-spar (A) is taken out; then, on looking through the eye-piece, we see, by means of the lens, a magnified image of the square aperture; but when the spar is inserted we see, not one image, but two images side by side (Fig. 10). It has been shown in the article on Calc-spar that when a ray of light enters a piece of this spar in any direction, save one, the ray becomes forked, or split up into two rays—one called the *ordinary*, and the other the *extraordinary* ray. In the dichroiscope we have, therefore, two images of the square aperture, and the piece of calc-spar is cut of such a length that these images just touch, but do not overlap. With this instrument we are enabled to examine the feeble dichroism of such minerals as the emerald.

Fig. 10.—Double Image of aperture seen through the Dichroiscope.

If a piece of green glass, or any non-crystallised substance, be held behind the square aperture, the two images seen on looking through the instrument will be identical in hue. Again, if a mineral crystallising in the cubical system, such as a coloured diamond or a green garnet, be similarly examined, it will in like manner yield two images of one and the same tint. In other words, all uncrystallised bodies, and all crystallised bodies which belong to the cubic or regular system, are *not* dichroic; but, on the contrary, all other minerals—all substances, in fact, which crystallise in any of the other five systems recognised by crystallographers—do exhibit dichroism or pleochroism to a greater or less extent. In the case of the emerald, the pleochroism is sufficiently marked to be serviceable to the observer in distinguishing this gem from other green stones.

Fig. 11.—Prism of Emerald, showing direction of optic axis.

To understand this phenomenon, it is necessary to refer again to the crystallisation of the emerald. The line A B, which runs lengthwise down the middle of the six-sided prism (Fig. 11) perpendicular to the two ends, indicates the direction of what is called the *principal axis* of the crystal; this is also its *optic axis*. It has been explained elsewhere† that along the optic axis there is no double refraction; and, in like manner, there is in this direction no dichroism. If, therefore, the emerald be viewed through the dichroiscope, along the axis A B, the two green images of the aperture present exactly the same tint and the same intensity of tint. The effect is the same as though we were examining a bit of green glass (which is not a crystallised body), or a green garnet or a green diamond—two gems which are related to the cube in the character of their crystallisation.

Applying the dichroiscope, however, to one of the side faces, at right angles to the surface, we observe, if not at first, at least on rotating the instrument, that the two images are of decidedly different tints. In the case of the emerald, one image is of greenish-yellow colour, while the other is of a greenish-blue hue. It is therefore possible, by means of the dichroiscope, to resolve the colour of the emerald into two tints, one containing more yellow, and the other more blue, than the normal

* For a description of this spar, see Vol. II., p. 348.

† "Science for All," Vol. II., p. 350.

green colour of this mineral; the former is the image due to the ordinary rays, the latter to the extraordinary rays.

It has been mentioned in the course of this article that the finest emeralds are obtained from South America. Prior to the Spanish conquest of Peru the number of these gems which found their way into Europe was probably very limited. According to the old Spanish chronicler, Garcilasso de la Vega, the ancient Peruvians worshipped in the valley of Manta a huge emerald, to which the multitude of worshippers, instigated by the priests, presented offerings of the choicest gems. Most of these emeralds were captured by the Spaniards, but it appears that the conquerors did not find the original locality. At the present day nearly all the emeralds that come into the market are obtained from the famous mines of Muzo, in the Colombian Province of Boyaca. These workings are situated on the eastern slope of the Andes, about seventy-five miles to the N.N.W. of the town of Santa Fé de Bogotà. There is another mine called Lasquez, two days' journey from Muzo.

The Muzo mines, after having been worked for untold generations, were stopped in the middle of the last century, nobody seems to know why. Rumours got abroad that fires had broken out in the mine, and that it would be dangerous to resume the workings; but as the immediate neighbourhood is not volcanic, such rumours were probably baseless. About the year 1844, a Colombian named Paris, bolder than his fellow-countrymen, visited the mine, and having obtained quantities of the gems, took them to Europe and to the United States, where they realised large sums. The mine was afterwards worked by a French Company, and all the fine stones found their way to Paris, where under the late Empire they were extremely fashionable, since green was the Imperial colour.

When the emeralds are first broken from the rock they are exceedingly fragile, and readily crack spontaneously, whence the profusion of flaws in most specimens. To prevent the stones from splitting, they are sometimes protected from the sun's rays on removal from the matrix, and allowed to dry very gradually.

At Muzo the emerald occurs in a dark-coloured fossil-bearing limestone, associated with calc-spar, iron pyrites, and a rare mineral called *Parisite*, which borrows its name from the enterprising Colombian previously mentioned. Two crystals of emerald, seated on the characteristic black rock of Muzo, and accompanied by calcite and pyrites, are represented in Fig. 12.

From what source were emeralds derived before the discovery of America? It is certain, whatever may be the doubts as to the gem having been known in the East before the discovery of Peru, that emeralds occur in a few localities in the Old World, though nowhere in such quantity or in such beauty as in South America.

Some years ago M. Cailland, a French traveller, discovered the remains of ancient workings for emeralds at Jebel Zabara, in Upper Egypt. Probably this locality supplied the early Eastern

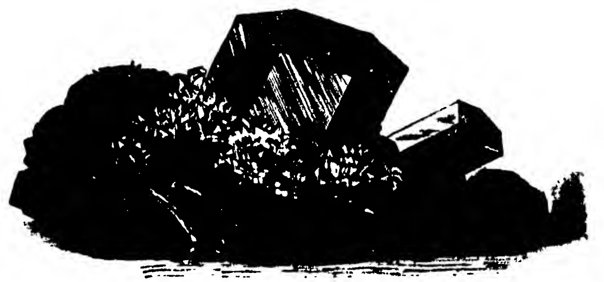


Fig. 12.—Emeralds.

nations with most of their emeralds. Pliny, for example, speaks of the Coptic and Ethiopic varieties. These workings were re-opened by Mohamed Ali, in the hope of unearthing some fine stones. When Belzoni, searching for the ruins of ancient Berenice, visited the locality, he found fifty miners at work; but the expectations of sanguine explorers not having been realised, the workings were eventually abandoned.

In 1830, some emeralds were discovered in the earth beneath the roots of a tree at Takowaja, near Ekaterinburg, in Siberia. This locality has since been diligently explored, and has yielded some very fine crystals. Probably the Scythian emerald of Pliny was obtained, as Mr. King has suggested, from the Ural and Altai mountains by the gold-seeking barbarians known as Arimaspi, by whom they may have been brought down to the Greek colonies on the Euxine or to the Persians on the Caspian Sea.

The emerald is also found in the Heubachthal in Salzburg, where it occurs, as in Siberia, embedded in mica-schist, while the coarser form known as beryl occurs sparingly in granitic rocks in Great Britain, and, among numerous localities abroad, is found in huge masses in Massachusetts, New Hampshire, and other parts of the United States.

From this enumeration of the principal localities for emerald and beryl, it will be seen that the true emerald is of excessively local occurrence. It is worth mentioning, however, that there are no known laws regulating the geographical distribution of minerals similar to those which rule the distribution of animals and plants. Climate has no influence upon the development of minerals, although some people, more fanciful than scientific, have held that the richest-tinted gems are found only in tropical climes.

In consequence of the rarity of the true emerald, it always commands a high price in the market, and, speaking generally, it may be said to rank next in value to the ruby and sapphire. True, it is not equal in hardness or in lustre to these stones, much less to the diamond, but its surpassing beauty of colour confers upon it a high value. It is, moreover, a stone which is seen to equal advantage by daylight or by artificial illumination.

In ancient times the emerald was valued not only for the magnificence of its colour, but also for the subtle virtues which it was reputed to possess. As a medicine its value stood so high that it was almost as much prized by the apothecary as by the jeweller. A dose of powdered emerald, varying from four to ten grains, was accounted a certain remedy against the effect of fever or plague, and was even an antidote to the most virulent of poisons. But the internal administration of the gem was only a gross way of exhibiting its virtues. Worn as an amulet, it was reputed to ward off evil spirits and to preserve the chastity of the wearer, to divert bad dreams, and impart courage to its possessor. Most stones of a green colour have at various times been the object of superstitious regard, and the emerald has especially been venerated. In these latter days the gem has lost much of its ancient prestige, but it still holds a very high place as a popular favourite. The preceding article, however, has shown that while the mists of superstition which formerly surrounded the gem have been dissipated by the rays of science, the stone is still possessed of physical and chemical properties which surround it with a brilliant halo of scientific interest.

THE FALL OF A STONE.

By William Durham, F.R.S.E.

THE time-honoured story of Sir Isaac Newton having had his attention directed to the laws of gravitation by the fall of an apple from a tree may or may not be true. The legend, however, points to a fact full of scientific meaning, that the grandest secrets of nature may be ascertained from a careful study of the most ordinary and every-day occurrences; and in this paper we shall endeavour to show that from "the fall of a stone" those great laws, the discovery of which have made Newton's name immortal, may be learned.

We are all aware that if we throw a stone straight up into the air its speed upwards gradually grows less and less, until it stops for an instant, then returns to the earth again with ever-increasing velocity until it strikes the ground. Now, let us suppose that just at the instant when the stone is at its greatest height, and when it is stationary, the earth were suddenly removed entirely away, and let us inquire what would be the behaviour of the stone. Most people would at once conclude that, of course, it would fall downwards and continue its course, there being nothing to arrest its progress. We all have such an instinctive notion that bodies ought to fall downwards when there is nothing to support them that such would seem the natural conclusion. A little consideration, however, will show us that this opinion is not so well founded as at first sight appears.

The earth being a globe or ball-like body, revolving on its axis once in twenty-four hours, it follows that, except in very high latitudes, our directions are completely reversed every twelve hours, so that what is up in the one case is down in the other. Suppose Fig. 1 to represent the earth revolving from left to right in the direction of the bent arrows. Now, an observer standing at A at twelve o'clock in the day would consider upwards to be in the direction of the top of the page and downwards in the direction of the bottom. At twelve o'clock at night he would be standing at C, and these directions would be completely reversed, so that upwards would now be towards the bottom and downwards towards the top of the page. A stone, therefore,

thrown up by this observer at twelve o'clock noon would fall in an exactly opposite direction to one thrown up at midnight. Further, at intermediate times, say at six p.m. and six a.m., the directions would be at right angles to those at twelve noon

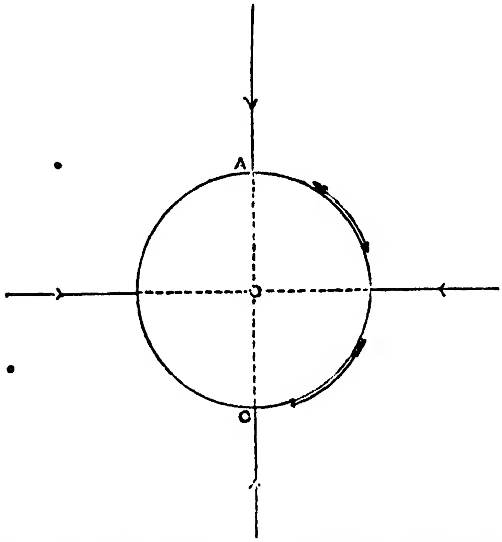


Fig. 1.—Illustrating the Relation of Gravity and the Revolution of the Earth.

and twelve midnight; these directions are shown by the straight arrows in the figure. We thus see that our notion of falling downwards is not correct in the ordinary sense in which we use it. Further, if we look at the directions of the arrows at the various times, we see that if these directions were prolonged they would meet in a point in the centre of the figure of the earth. We are therefore justified in concluding that when a stone falls it is drawn or attracted towards the centre of the earth. If this conclusion be correct, then it is evident the motion of the stone is really due to the presence of the earth, and if, as we have supposed, the latter were suddenly withdrawn when the stone was for the instant without motion, the stone would just remain in exactly the same position as it was; there would be neither upward nor downward motion. The correctness of this idea will be strengthened if we consider the stars and planets, which are really in the position of the stone we are considering, unsupported in space, and although they move in a manner afterwards to be described, they do not fall out of their places as we have imagined the stone might do. From these considerations we arrive at the law that a stone or, indeed, any body *will remain exactly in the place where it is put, provided no force from without acts upon it.*

Advancing a step further, let us next consider what would be the behaviour of the stone if the earth were suddenly removed, not at the instant when it was motionless, but when it was moving with some velocity towards the earth. Here, again, we might be tempted to conclude that when the earth, the cause of the motion, was removed, the motion would cease and the stone would come to a standstill; but here, again, further consideration would change our ideas. We know from experience that when any body is moving, such as a cricket- or cannon-ball, we require to exercise considerable force of resistance to stop it. We observe also that the falling stone gradually increases in velocity as it approaches the earth. This shows us that the attraction of the earth is gradually accumulating force in the stone, so to speak; the effect produced during the first second remaining in the stone, while the effect during the second second is added to it, and it is only the resistance offered by the solid ground that prevents the stone from continuing its onward course. It is evident, therefore, that, in the case supposed, if the earth were suddenly removed the stone would continue its onward course with unabated speed, not, however, increasing the speed at which it happened to be moving when the earth was withdrawn. We thus attain to a second law: that *any moving body will continue that movement without either increase or diminution provided no force from without acts upon it.*

From these two laws we arrive at the knowledge of the fact that matter of any kind is quite inert, has no inherent power to change its state. If it is put in any position, there it remains; if moved in any direction or at any speed, in that direction and at that speed it continues to move. It adds nothing, it takes away nothing, from any force communicated to it, but simply acts as a carrier, receiving and delivering up with rigid exactness whatever may be committed to its charge. This inertness of matter is at the foundation of all physical philosophy and all mechanics, and it is of great importance we should thoroughly grasp and understand it.

Turning our attention once more to the falling stone, let us consider more minutely its behaviour on approaching the earth; let us note its velocity during a fall of one, two, or three seconds. It has been very accurately determined that a stone under the action of the earth's attraction for one second will pass through a space of about 16 feet, and will at the end of the second be moving at the rate of 32 feet per second, that is, it would continue to move at that rate if the earth were suddenly

removed out of its way. At the end of two seconds it will have passed through a space of 64 feet, and its velocity will be 64 feet per second. At the end of three seconds the space passed through will be 144 feet and the velocity 96 feet, and so on. Tabulating these results we at once become aware of an exceedingly regular law, viz., that the velocity increases 32 feet every second, while the space passed through increases as the square of the number of seconds.

No. of Seconds.	Space Fallen Through.	Velocity Acquired.
One	16 ft.	32 ft. per sec.
Two	$16 \times 2 \times 2 = 64$ ft.	$32 \times 2 = 64$,,
Three	$16 \times 3 \times 3 = 144$ ft.	$32 \times 3 = 96$,,

During two seconds the body does not fall through twice 16 feet, but through four times 16 feet, and 4 is the square of 2, and so on, with three, four, or any number of seconds. Now, this result entirely confirms what we have said about the inertness of matter. Consider the space fallen through in two seconds, for instance. In the first second it has passed through 16 feet, and has acquired a velocity of 32 feet; going on, from its inertness, at this velocity, it passes through 32 feet in the next second, but at the same time the attraction of the earth causes it to pass through another 16 feet; this, added to the 32 feet, makes altogether 48 feet passed through in the second second, and this, added to the 16 feet first passed through, makes 64 feet the distance found by experiment. Thus the whole motion is accounted for. The same thing will be found in any number of seconds. The falling stone obeys exactly the force impressed upon it, neither adding to nor taking from it.

We have thus followed the movement of the stone in falling towards the earth, and traced the laws of its motion. If we now study the converse problem, viz., the rising of the stone from the earth, we shall reach the same conclusions; for we find that if we throw a stone upwards with a velocity of 32 feet per second it will rise to a height of 16 feet, and if with a velocity of 64 feet it will rise to 64 feet, and so on, these being the heights exactly from which it must fall in order to acquire the velocities of 32 or 64 feet per second with which it starts in its upward flight. Thus we see the attraction of the earth subtracts from it a velocity of 32 feet per second. We say, then, the earth's attraction is such that it produces a velocity of 32 feet per second on any body free to fall at its surface.

We have thus far considered only the movements of a stone thrown vertically or straight upwards; we shall now study its movements when thrown somewhat off the straight line—at an angle, as it is called. In this case, instead of falling straight down to the earth again, it takes a peculiar curved path, something like Fig. 2, called a parabola, the result of the two forces acting on it: the one the force with which it is projected in the direction A B, and the other, B D, the force of gravity drawing downwards to the centre of the earth. Now the horizontal distance to which the body will attain before it touches the ground again depends on the force with which it is projected. Thus a cannon-ball shot out with a great velocity will go very much

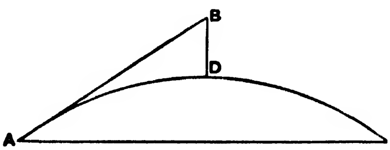


Fig. 2.—Illustrating Movement of Stone thrown at an Angle.

further than a stone thrown by the hand at the same angle. Now we may imagine the force of projection to be increased to such an extent that the stone or ball would go right round the earth in a circle without touching it. Now, in this case we can easily see that the attraction of the earth only causes the stone or ball to take a circular path; it takes nothing from the original velocity, for the body in the case supposed never alters its distance from the earth, and we have seen that it is only when the earth's attraction acts against the body rising from its surface that the velocity is lessened. The stone or ball therefore will, after going right round the earth, still have the same velocity as at starting, consequently it will continue to revolve round and round for ever. The stone is continually, as it were, attempting to fly away in a straight line, but the attraction of the earth restrains it, and guides it into a circular path, just like a stone in a sling, the string of the sling acting the part of the earth's attraction in restraining the stone while it is whirled round in a circle. Now the force with which the stone tends to fly away from the earth is termed "centrifugal force,"* and it is very evident that to keep the stone revolving round the earth the centrifugal force must be exactly balanced by the force of attraction, for if the former were stronger the stone would fly off into space, and if the latter it would be drawn onwards to the earth. For instance, if a body is projected vertically upwards with a velocity of 472 miles per minute

* "Science for All," Vol. III., p 153.

gravity will never be able to restrain it, but it will pass away into space and never return; if projected at an angle with the same velocity its path will be a parabola, but it will never return to the earth; if with rather less velocity it will revolve round the earth in an ellipse of immense extent. As the initial velocity is reduced the curved path will be less and less, till it revolves in a path nearly circular when the two forces are nearly balanced.

It must be noticed, however, that all the laws we have traced out are only strictly correct when the movements take place in a vacuum; they are greatly modified by the resistance and friction of the atmosphere. In falling through the air we find a stone does not fall at the same rate, nor would the same force cause it to go completely round the earth if it had to pass through the air. In fact, unless the force were so great as to drive it beyond the atmosphere altogether, it must sooner or later fall in upon the earth. The importance of this fact will be recognised as we proceed.

The next point we must consider is the effect of distance on this force of attraction. Would a stone, for instance, falling at a height of a mile or two above the earth's surface, acquire a velocity of 32 feet per second, as happens when it is near the surface? This point has been settled by experiments at different heights, made with the pendulum, which in reality vibrates on the same principle as a stone falls. It is found that the force of gravity diminishes exactly as the square of the distance from the earth's centre increases. Thus at twice any distance from that centre the attraction is only one-fourth, at three times the distance it is one-ninth, and so on.

Further, it has to be observed that all bodies, whatever be their mass or quantity of matter, follow these same laws of gravity; thus, cork falls as rapidly when unopposed by the air as lead does. This shows that the attraction of gravity is proportional to the mass of the falling body, for it is clear that if a body of two pounds weight moves at the same speed as a body of one pound weight, the force exerted in the former case is double that of the latter.

Another curious result of the action of gravity is this: when we project a stone into the air we actually move the world. There are familiar instances of this principle all round us. A shot fired from a gun or cannon* causes the latter to "kick," or recoil, as it is termed—the force of projection acts equally in driving the bullet forward and the gun backward; similarly, when we throw a stone into the air we at the same time, as it were, kick the earth in the other direction, and when the stone returns again, drawn down by the attraction of the earth, it also attracts the earth to itself, and the approach is mutual. There is a point between the centre of the earth and the stone called the centre of inertia, which never varies its relative distance from the centre of either. We may form some idea of this from considering a long lever rod with a small weight at one end and a large one at the other, and supported at a point between them so that they are exactly balanced. If we move the smaller weight to or from the point of support we must also move the larger one in the same way, proportionately to its size. Now this gives us some idea of the action of throwing a stone; the point of support must keep steady; the stone is represented by the smaller weight moving along the arm of the lever and the earth by the larger, and we thus see that their movement must be mutual and inversely proportional to their relative masses.

When Newton had arrived at the knowledge of the laws of gravity which we have described, it naturally occurred to him that as gravity did not cease to act even at a considerable distance above the surface of the earth it might continue to act at great distances in space, and he directed his attention first to the moon, as the nearest body to the earth, and yet not part of it. He thought it might possibly just be like the stone projected with such force that it revolved round and round the world for ever. Now, we have observed that a falling stone is acted upon by a force tending towards the centre of the earth, and if the moon is really in the position of such a stone it must show by its motion that it is acted upon by a force proceeding from that centre, or appearing to do so; for we must remember it is not the centre that really attracts, it is the whole earth that does so, and the combined result is the same as if it all proceeded from the centre. Now, if the moon's path were exactly circular, the action from the earth's centre would be evident at once, for consider Fig. 3, where the outer ring represents the moon's path and C the centre of the earth. Suppose the moon at M as a falling body, acted on by the earth's attraction alone, falls, say in a second, to the point N; but it has centrifugal force from its original motion, which in that same time would carry it, say, to P. Now, these two forces acting at once would, according to the well-known law of mechanics, carry the moon M to the point O. Thus we would

* "Science for All," Vol. II., p. 222.

have evidence of the attractive force directed to the earth's centre. The moon's path or orbit round the earth is not, however, exactly circular; it is elliptical, or oval, from which it is evident the moon must be nearer the earth at certain times than at others. As gravity increases the nearer bodies approach one another, it follows that the moon would be drawn into the earth altogether

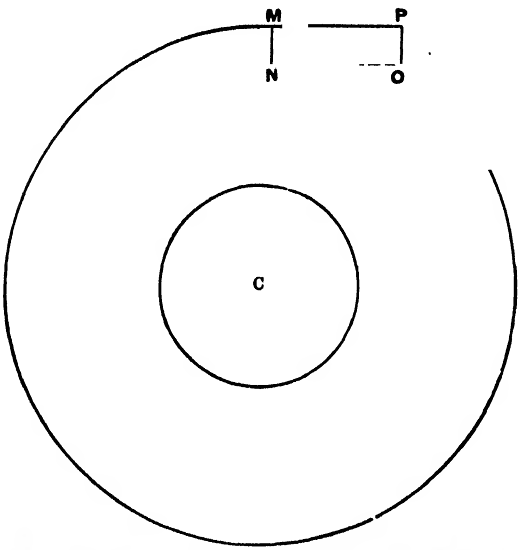


Fig. 3.—Illustrating the motion of the Moon round the Earth.

when it came nearer, unless there was some counteracting influence. Now, this is found in the increased speed with which the moon travels in its course when coming nearer the earth, and that in a certain regular manner which the law of gravity requires in a body moving round a fixed centre. Fig. 4 will make this plain. Suppose a body moving in a straight line, A B, at a certain fixed rate, it is evident it will travel equal distances along the line in equal times. If we take these equal distances, and join them to the centre S, geometry tells us that the various triangles, A S C, C S D, &c., will also be equal. Now if, instead of moving along a straight line, the body is drawn in towards the centre, the law of motion by which a body neither loses nor gains and the law of gravity require that the new triangles formed should be equal to the former ones, so that the increased space passed over by the body when it is nearer the earth should exactly make up for the diminished distance from the earth. Thus the triangle A S E must be equal to the triangle A S C, &c. This is found to be the case with the moon in its motion round the earth, and is usually stated thus. The line joining the centres of the earth and moon describes equal spaces in equal times.

Thus far the moon seems to obey the laws of gravitation already described, but more must be proved. It is necessary to show that the force of gravity at the distance of the moon from the earth is exactly equal to what we have called the centrifugal force, or the tendency the moon has to fly away in a straight line into space. The centrifugal force can be easily known from observing the moon's speed. In making this calculation at first, Newton found that the two forces did not balance each other, and as an evidence of his exceedingly scientific mind, he, for a time, laid aside his theory, as facts were against it—a truly noble lesson for all scientific speculators who are only too apt to make facts square with theories instead of theories with facts. An error in the supposed distance of the moon, however, having been discovered, Newton saw at once that, with this corrected, his theory would be in complete accordance with the facts. It is related that he was so excited by the circumstance that he was unable to finish his calculations, and had to get a friend to do it for him.

We have mentioned that the moving path round the earth is not circular, but elliptical, or oval. Now, this also necessarily follows from the laws of gravitation. For suppose the moon at such a dis-

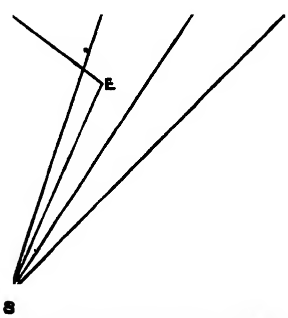


Fig. 4.—Illustrating the motion of the Moon round the Earth.

tance from the earth that its speed is reduced so much as no longer to possess sufficient centrifugal force to balance the earth's attraction, it will necessarily commence to fall towards the earth like a stone, and, according to the laws we have traced, its speed will increase. Now it can be easily shown that this speed will increase the centrifugal force faster than the attraction of gravity increases by its approach to the earth, consequently it will commence again to recede from the earth, and this backward and forward movement generates the peculiar path it takes.

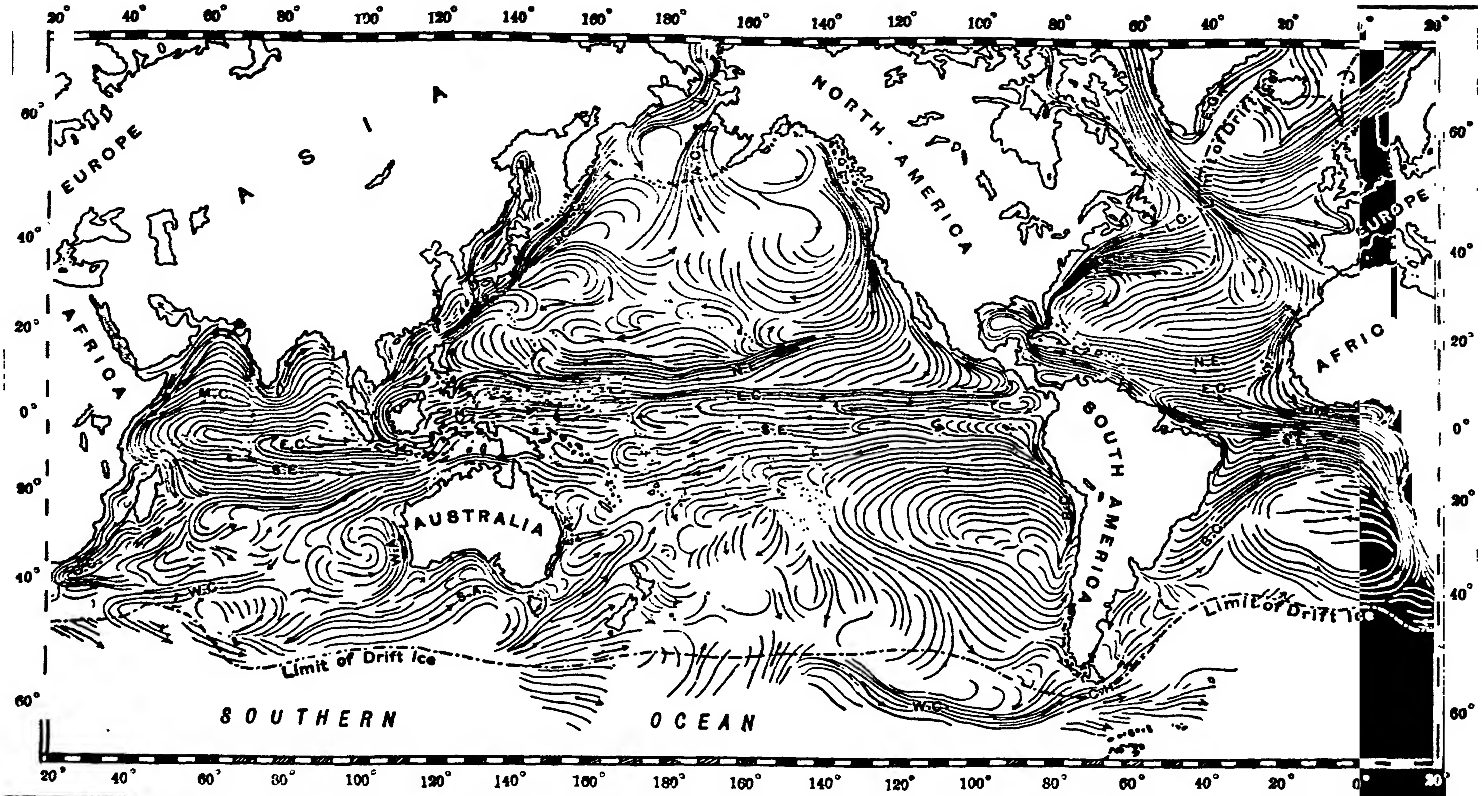
The great secret of the universe is thus fairly discovered, and only the details require to be worked out, for the moon's path round the earth is, on a smaller scale, what the paths of the planets are round the sun, and the solar system is by every principle of analogy representative of the vaster systems of the fixed stars. All are governed by what seems the fundamental principle of matter, viz., that *every body attracts every other body with a force proportional to their masses, and inversely as the square of the distances between their centres.* This great general law supplies us with the key with which we can unlock every difficulty, and enables us to predict with almost absolute certainty the movements of the heavenly bodies. In no case has it failed, or seemed to fail, though tested in every possible way.

What we have already learned from "the fall of a stone," though important enough, by no means exhausts the subject. There is another field of inquiry developed in more recent times to which this phenomenon naturally leads us. We noticed that the stone in falling accumulated, so to speak, the force of gravity in itself, so that it would go on moving even were the earth's attraction removed after it was in motion. We noticed also that the stone was, of course, stopped in its course when it struck the ground. Now the question arises, what becomes of the force with which the stone was descending? All visible motion ceases; is the force, therefore, entirely lost and annihilated? The answer to this question is the greatest advance, perhaps, that science has made in modern times. It had always been observed that hard bodies, such as stones, when sharply struck one against the other, emitted light, but the full significance of this fact has only lately been perceived. The light and, of course, the heat developed with it are found to be the exact equivalent of the force of the collision of the bodies. When, therefore, a stone falls to the ground the visible motion is not lost, but is entirely changed into the invisible motion of the particles of the stone which we term heat. We find, therefore, that when the stone is arrested in its course its temperature is raised, and there is always an exact relation between the distance fallen and the amount of heat. Now, this relation has been carefully studied and measured, and it is found that when a pound weight of any body falls through a space of 772 feet by the earth's attraction it generates enough heat to raise one pound of ice-cold water 1° Fahr., or 772 lbs. falling through one foot generates the same quantity of heat. This has been called the "mechanical equivalent of heat," because it enables us to measure the value of heat in mechanical work, and is of great importance in the practical application of heat to the driving of machinery.

Now, since the fall of a stone upon the earth generates a certain amount of heat, we may imagine the fall of an immense number of such stones generating so much heat as to cause the earth to glow and shine as the sun does with its own inherent heat. Nor is it necessary that the fall should be rapid and over in a short time, for as a certain amount of motion is always represented by its equivalent in heat, we may imagine these stones falling together towards the centre of the earth in a very slow manner, but clashing among themselves, and having the appearance from the outside of a gradual contraction in volume, and still the heat and glow kept up for a length of time. Now, it is extremely probable that the heat of the sun has its source in this action of gravity, gradually contracting its volume, and giving out its force as heat and light. The source of the sun's heat has long been a puzzle to scientific men, and this action of gravity seems to supply the best solution of the difficulty. If this be so, then we have another evidence of the wide dominion of the laws of gravity in the light of the stars, for if the sun's light and heat be due to this cause, that of the stars must be due to the same all-pervading force.

In such immense bodies as the sun and the fixed stars, a contraction in volume scarcely perceptible for many ages, would supply a sufficient quantity of heat to keep their light practically undiminished.

The principles involved in the fall of a stone throw light on another strange and puzzling class of bodies belonging to the solar system. We mean the comets. These bodies revolve round the sun in very eccentric elliptical paths, and this, we have seen, is the kind of path a stone would take if hurled with sufficient velocity from the surface of the earth at an angle from the vertical or straight upward direction. They may therefore have been projected from the body of the sun by the action of its internal forces. Their paths are governed strictly by those laws of gravity we have already described. It has been proved by spectrum analysis that these bodies not only reflect the solar light but shine from their own inherent high temperature, and it has been suggested by Professor Tait, that this temperature may be explained by the supposition that comets are composed of nothing more nor less than showers of stones rushing among themselves



J.J. Wild del. T. E. Co. Sc.

FIG. 1.—CHART OF THE SURFACE-CURRENTS OF THE OCEAN.

INDIAN OCEAN.

CC, Cape Current, or Agulhas Current.
MC, Malabar Current.
EC, Equatorial Counter-Current.
SE, South Equatorial Current.
WC, Westerly Current.
WA, West Australian Current.
SA, South Australian Current.
←, Westerly Direction of Currents during N.E. Monsoon.
→, Easterly Direction of Currents during S.W. Monsoon.

PACIFIC OCEAN.

KS—JC, Kuro Siwo, or Japan Current.
EC, Arctic Currents from Behring Sea.
NE, North Equatorial Current.
EC, Equatorial Counter-Current.
SE, South Equatorial Current.
PC, Peruvian Current.
EA, East Australian Current.
WC, Westerly Current of the Southern Ocean.

ATLANTIC OCEAN.

LC, Labrador Current.
EG, East Greenland Current.
GS, Gulf-Stream.
NE, North Equatorial Current.
EC, Equatorial Counter-Current
GC, Guinea Current.
SE, South Equatorial Current
SA, South Atlantic Current.
BC, Brazil Current.
CH, Cape Horn Current.

possess an instrument for finding out the direction and speed of an under-current by direct observation. By indirect means, however, he has been enabled to obtain an insight into what is taking place in the great depths of the ocean, namely, with the help of the deep-sea thermometer, which registers the temperature of the water at all depths from the surface down to the bottom of the sea. If, with the aid of this instrument, he discovers the existence of cold water in the seas between the tropics, he is naturally led to suspect that this cold water must have originally come from higher and colder latitudes; or if, by the same means, he discovers warm water in the Polar seas, he is justified in concluding that it must have come from the warmer regions of the earth's surface; in other words, he comes to the conclusion that there must be currents of cold water flowing from the Poles towards the Equator, and warm currents flowing from the Equator towards the Poles. Observations made with the thermometer in a great many parts of the ocean prove beyond doubt the existence of these currents. The cold water found in the depths of tropical seas has been traced step by step to its original home in the Polar seas, and, *vice versâ*, the warm currents which undermine the glaciers and ice-floes of the Polar regions have been followed up to where they issue from the tropical belt. In this manner the deep-sea thermometer has brought to light a number of very remarkable and quite unexpected facts. For example, under the Equator, the water between 100 and 500 fathoms below the surface has been found to be much colder than water at the same depth in the seas immediately outside the tropics. Thus, the temperature of 41° Fahr., which under the Equator and in the Atlantic Ocean is observed at a depth of 400 fathoms, is in the Bay of Biscay not obtained until a depth of 800 fathoms is reached. In the Polar seas we find below the cold surface-waters a stratum of water of a higher temperature, and going farther down we again meet with cold water. It has also been ascertained that the waters which fill the depths of the ocean from 1,000 fathoms down to the bottom at 2, 3 and 4,000 fathoms are, with the exception of some inland-seas, of a temperature only a few degrees above the freezing-point. In this manner the solid globe of this earth is wrapped in a sheet of ice-cold water of a thickness varying from 2 to 3 miles, which in its turn is covered with a comparatively shallow layer of warm water, spreading out on both sides of the Equator, and disappearing in the vicinity of the Arctic and Antarctic Circles

The most important conclusions which we may draw from these facts revealed by the deep-sea thermometer are: that the currents of the sea are thermal streams, by means of which heat and cold are distributed through the entire domain of the ocean; that oceanic currents may be divided into surface-currents and under-currents, and that the same current may alternately assume both characters, now flowing at the surface of the sea, now sinking below other currents and continuing its way in the depths of the ocean. Some day it may be possible to construct a chart of under-currents as a necessary complement to the chart of surface-currents given above, but the observations made up to the present are not as yet sufficient for this purpose, although considerable progress has been made in this direction. For instance, the thermometrical soundings made by the officers of the United States Survey along the east coast of North America show that the Arctic surface-current, known as the Labrador current, sinks below the waters of the Gulf-stream and after sending offshoots into the Gulf of Mexico and the Caribbean Sea it disappears in the depths of the tropical Atlantic. Another great current issuing from the seas of the Antarctic has been traced by the officers of H.M.S. *Challenger* flowing as an under-current along the east coast of South America from the Falkland Islands to the St. Paul Rocks near the Equator.

The nature of the sea-bottom having been already described,* we may now briefly narrate as far as our space will admit of, the various explanations which have been given of these currents. Unhappily, however, owing to theorists trying to account for the motion of the rivers of the sea, by reasonings founded on a single phenomenon, to the absence of trustworthy observation until recently, and to the non-recognition of the fact that the ocean currents have changed in course of time, few writers are at one in their explanations of the facts which they detail.

Among the various causes which tend to produce currents in the ocean and determine the direction in which they flow is the unequal distribution of the sun's heat over the earth's surface. It is well known that on account of the spherical shape of the earth, the equatorial regions receive a much larger amount of heat from the sun than the polar regions, the amount of heat received varying from a maximum between the tropics to a minimum within the arctic and antarctic circles (Fig. 2). Water is a great

* "Science for All," Vol. III., pp. 76, 159.

storer-up of heat, hence we find that the surface-waters of the ocean within the tropics are raised to a high temperature, as much as 80° Fahr., while in the polar regions their temperature is reduced to freezing-point and the water is transformed into ice.

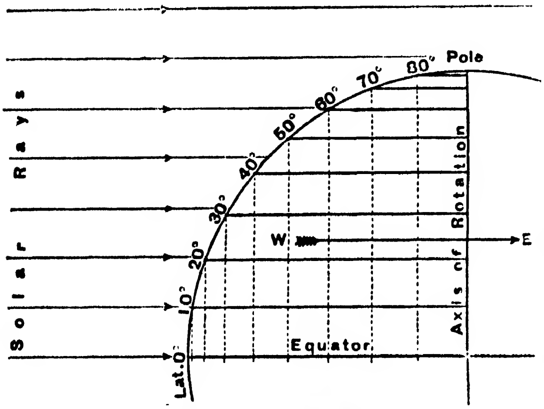


Fig. 2.—Diagram showing the unequal Distribution of the Solar Rays over the Earth's surface, and the Gradual Shortening of the Radius of Rotation from the Equator to the Pole

Again, in the act of absorbing heat, water becomes lighter, that is to say, a stated volume of water when heated weighs less than an equal volume of cold water. As the waters of the sea under the influence of gravity always tend to maintain a perfect level, and as bodies of different weight cannot balance each other, the warmer and lighter surface-waters of the tropical seas flow over into the adjacent cooler seas; but becoming cooler as they reach higher latitudes, they will again become heavier and return in the shape of under-currents, in order to replace the volumes of water constantly being removed by the above-mentioned outflow from the tropics. In this manner it can be explained how the unequal exposure of the different parts of the earth's surface to the rays of the sun, must result in the creation of warm currents flowing from the Equator towards the Poles, and of cold return-currents running in the opposite direction.

But the actual direction of these currents is determined by a cause which seems to exercise an influence upon all oceanic currents flowing either north or south, namely the daily rotation of the earth round its axis. The speed of this movement is naturally greatest at the Equator and reduced to zero at the Poles. For instance, a point on the Equator rotates at the rate of about 1,000 miles per hour; one situated on the parallel of 60° latitude, the length of which is equal to half the circumference of the Equator, moves at the rate of nearly 500 miles an hour; while a point 7 miles from the Pole moves in the course of 24 hours through a circle of 22 miles, or at a rate of less than 1 mile an hour. If, now, we follow a current flowing from the Equator towards the Pole, it is evident that this current will at every step of its progress arrive with a rotatory speed from west to east greater than the speed proper to the latitude at which it has arrived; in other words, it will rotate faster than the earth upon the parallel which it has reached, and in consequence it will acquire a tendency to flow towards the east. The decrease in the rotatory speed is inconsiderable until we reach the twentieth parallel on each side of the Equator (Fig. 2), beyond which, however, it diminishes rapidly, and it is just here, as a glance at the map will show, that equatorial currents bend round and take a more and more easterly turn as they advance into higher latitudes. It is this easterly tendency which causes these currents to press up against, and to flow along the west coasts of the continents and islands which stretch across their path.

Let us now see what happens to a polar current as it issues from the Frozen Ocean and proceeds towards the tropics. It passes from a higher to a lower latitude with a rotatory speed greatly inferior to that of the parallel which it has just reached. In consequence it will lag behind the more swiftly rotating earth and assume a decided tendency towards the west. We therefore find that polar currents flow towards the south-west and west, and press up against and are compelled to follow the east coasts of the continents and islands which they encounter in their path. As the current approaches the tropics, however, the difference between its own rotatory speed and that of the parallel at which it arrives becomes gradually less, and on nearing the Equator it begins to rotate as fast as the earth itself, that is to say, it gradually loses all tendency to lag behind or to flow towards the west, and, sinking down on account of its own superior gravity, it disappears below the lighter and warmer waters of the equatorial belt.

This system of thermal circulation which, as we have just endeavoured to show, embraces the whole ocean, and keeps its waters in perpetual motion, is greatly modified and to some extent obscured by the action of another agent known as being a constant cause of currents in the sea, namely the winds. That the latter have the power of inducing currents at the surface of any sheet of water over which

they blow, is a fact which must be familiar to every reader, and it is equally well known that the speed, volume, and direction of these currents immediately depend upon the speed, duration, and direction of the winds by which they are caused. The stronger the wind is and the longer it blows, the swifter and deeper the current is; while the direction of both is the same. For this reason a strong wind at sea will often produce a surface current flowing in a direction different from, and sometimes opposite to, the direction of the oceanic current over which it blows.

Space will not permit us to enter here into a description of the atmosphere and of its currents, or winds. It may be sufficient to recall the fact that it forms an aerial envelope the thickness of which, although it much exceeds the greatest depth of the sea, is still so small when compared with the diameter of the earth, that we must conceive the atmosphere as a thin layer spread out over sea and land, and enveloping the whole terrestrial globe. The winds obey the same physical laws as the currents of the sea, and are similarly affected by the unequal distribution of solar heat and the diurnal rotation of the earth. They also assume in turn the character of upper and under currents, and as they blow over the surface of the sea they produce oceanic surface-currents flowing in the same direction in which they blow. This is why we find on looking at our current-chart that most of the great surface-currents of the sea correspond exactly with the permanent or periodical winds which flow in the same region of the earth's surface. Thus the North and South Equatorial Currents correspond with the N.E. and S.E. Trades, the westerly currents of higher latitudes with the Anti-Trades and westerly winds of the same parallels, the periodical currents of the Indian Ocean and the China Sea with the N.E. and S.W. Monsoons which alternately prevail in these seas.

Another cause which, in a less conspicuous though not less effective manner, assists in the formation of oceanic currents is the difference which exists between the seas in the tropics and those of higher latitudes as regards the quantity of salt which they hold in solution. The evaporation which takes place on such a vast scale beneath the rays of a tropical sun renders the water of the equatorial seas more salt and therefore more heavy, while the abundant precipitation in the shape of rain and snow of the temperate and polar zones makes the sea-water in these latitudes fresher and lighter. This difference in saltness is accompanied, as we have shown on a former occasion,* by a change of colour, the briny seas of the tropics being distinguished by a beautiful deep-blue tint which, as the proportion of salt decreases, changes by degrees to the greenish-blue, bluish-green, and green colours of the seas situated in higher latitudes. This increase or decrease in weight due to the varying degree of saltness is, however, more than counterbalanced by the effects of temperature, for the warm salt water of a tropical current is lighter than the cold and fresher water of a polar current.

Among the remaining conditions which affect the course of the rivers of the sea are the direction of the coast-lines and the general shape and dimensions of the oceanic basin through which they flow. A glance at our current-chart suffices to show that most currents are diverted from their original course by the great continents which, extending from north to south across the Equator, separate the different oceanic basins from each other. A comparatively slight alteration in the direction and extent of the coast-lines of these continents would suffice to completely change the flow of the currents. If, for example, the east coast of South America were continued from Cape St. Roque beyond the island of Fernando Noronha as far as St. Paul Rocks near the Equator, then the whole of the South-Equatorial Current, a portion of which now finds its way into the North Atlantic, would be diverted into the South Atlantic. Again, in many parts of the ocean a slight rise or fall in the level of the sea-bottom would cause such a change in the outline of the adjoining land as to considerably alter the direction of the currents, and there is sufficient evidence to show that changes of this nature have occurred during the past and are taking place even at the present day.

Finally, the most obvious of all causes of currents is that which arises from the necessity of maintaining the equilibrium between the waters of all parts of the ocean, for whenever a quantity of water is removed from one part of the sea either by evaporation, by the winds, or by oceanic currents, it is absolutely necessary that it be replaced by an equal quantity of water flowing in from another part. To this necessity we are inclined to ascribe the existence of the Equatorial Counter-Currents (Fig. 1) which in the Pacific, Indian, and Atlantic Oceans flow from west to east in the equatorial belt of calms. The vast volumes of water which the north and south equatorial currents are constantly transferring from the eastern

* See "Science for All," Vol. III., p. 18.

to the western side of these oceans, must be replaced by return-currents flowing from west to east in the space left beween the trade-currents, and it is probable that the equatorial counter-currents above mentioned are intended to effect this compensatory movement. At least, until now, no more satisfactory and intelligible explanation of these counter-currents has been offered.

The rivers of the sea, apart from the astonishment and wonder which their stupendous proportions must arouse in the mind of the student of nature, present themselves to us as a subject of paramount interest, when we consider the part which they have played and are still playing in the building up of the topmost layer of the solid earth-crust, in the perpetual changes of climatic conditions, in the distribution of vegetable and animal life over the surface of our planet, and last, not least, in the recent advance of ocean-navigation, by which the inhabitants of the most distant lands have been brought into close intercourse with each other.

The erosive action of currents constantly tends to alter the configuration of the coast-lines, by taking away land in one place and depositing it elsewhere. Again, immense quantities of sediment carried by all the rivers of the world into the sea, are taken up by the currents and spread over the bed of the ocean. Geologists tell us that nearly all, if not all the dry land at present existing has at one time been at the bottom of the sea, an assertion confirmed by the fact that the strata which compose some of the loftiest mountain-ranges have evidently been deposited in ages long past upon the floor of the ocean and still retain the remains of the animals which disported themselves in the seas of former days. What we are still in the habit of calling "terra firma" is proved by modern observations to be in constant motion, rising and falling like the heaving breast of some mighty monster, whose arms stretch far beneath the waves. By the action of subterraneous forces, as yet unexplained, vast areas of the earth-crust are depressed below or lifted up above the level of the sea, and we are beginning at last to understand the truth of the maxim, that there is nothing stable in the universe of created things except the unstable.

The rivers of the sea, as we have endeavoured to show, are thermal currents conveying the solar heat stored up in the seas of the tropics into higher and colder latitudes and, in return, carrying the cold of the polar regions into southern latitudes in order to temper the heat of the Torrid Zone. But for this provision, the accumulated heat of the tropics and the accumulated cold of the regions bounded by the Arctic and Antarctic circles would be equally incompatible with vegetable and animal life, which now, thanks to the mitigating effect of the currents of the ocean, is able to flourish in every part of the earth to which the latter have access, and even in regions at a distance from the sea, for the winds, which are either warmed or cooled by their contact with oceanic currents, extend the tempering influence of the latter far inland.

There is indisputable evidence that the British Islands and the greater part of Europe were at one time covered with icebergs and glaciers, and that an arctic climate prevailed as far south as the shores of the Mediterranean. But we have also abundant proof that at a still earlier epoch not only Europe but the lands situated within the Arctic Circle must have enjoyed a tropical climate, for the numerous fossil remains found in these regions are those of plants and animals which, according to the present state of our knowledge, must have lived under conditions now only found in the tropics. Such a great change in the climate of the same region naturally gave rise to much speculation, and all the resources of cognate sciences were drawn upon in search of a satisfactory explanation. The whole solar system, as it were, was put out of joint and the terrestrial globe turned upside down in the hope of finding the cause of these climatic revolutions. It is true eminent scientific authorities* had already asserted the intimate connection between climate and oceanic currents, but the influence of the latter was not considered sufficient to account for the change from a tropical to an arctic climate and *vice versâ*. However, since the deep-sea thermometer has confirmed the existence of these currents by more trustworthy data, previously not available, and has revealed the movements of the enormous volumes of warm or cold water which are constantly being transferred by them from one part of the ocean to another, it has been possible to form a more correct estimate of the influence of currents upon climate. From the changes which are known to have occurred during past ages in the distribution of land and water all over the surface of our globe, we may conclude that the currents of the sea must have formerly flowed in different directions, and that their speed and volume

* See Sir Charles Lyell, "Principles of Geology," bk. i. c. vii. Dr. W. B. Carpenter, "Preliminary Report of the Scientific Exploration of the Deep Sea," by H.M.S. *Porcupine*, during the summer of 1869. Proceedings of the Royal Society, No. 121.

also must have varied at different epochs. We may therefore readily conceive that, at a time when certain regions—for example, the British Islands and western Europe in general—were exposed to the direct influence of Arctic currents, their climate must have been very different from what it was when their shores were bathed by the accumulated waters of an Equatorial stream: in fact, a difference equivalent to that between an Arctic and a Tropical climate; for the difference of temperature which determines the existence or non-existence of certain vegetable and animal organisms in a certain region, taking also into account the power which these organisms possess of adapting themselves to slow and gradual changes of climate, is a difference of only a few degrees (perhaps not more than 20° C.) of the thermometric scale, and not more than the difference of temperature between an Arctic and an Equatorial current. We ought also to remember that such a change in the currents of the sea could not take place without entailing similar changes in the winds or currents of the atmosphere, in the distribution of moisture, whether in the shape of rain or snow, and indeed, in all those conditions the combined influence of which we sum up under the name of climate.

The rivers of the sea, we have said, play an important part in the distribution of vegetable and animal life over the earth's surface. Ancient philosophers have suspected, and modern science asserts, that the ocean is the great storehouse of organic life, and that the ancestors of all that lives and moves upon land and in the air at one time dwelt in and drew their nourishment from the waters of the mighty deep. But this is a theme too vast for our present purpose. The agency of currents in transporting the seeds of plants, and even living plants, is, however, a fact familiar to every reader. Often the traveller upon the ocean, especially in the calmer seas of the tropics, falls in with tiny fleets composed of branches, leaves, fruits, seed-grains, &c., gently borne upon the waves until at last they are left upon the shore of some distant land, or drift into the sheltered lagoon of a coral-reef. In this manner the countless islands scattered far and wide over the surface of the ocean are supposed to have become fertilised and prepared for the habitation of animals and man.

In conclusion, we may allude to the fact that the more accurate knowledge obtained in our days of the rivers of the sea has given a great stimulus to ocean-navigation, by enabling the mariner to reduce the time of his passage from one port to another, and thus considerably to diminish the risks and dangers inseparable from a sea-voyage. The rivers of the sea now form the great ocean high-roads along which a never-ending procession of ships of all nations and of every size, from the stately liner to the rakish yacht, may be seen winding its way to distant climes. Within the last thirty years the journey from England to the Antipodes has been shortened from 120 days to little over forty days, and the modern navigator, by selecting the track where the currents of the sea and the currents of the air are most favourable to his progress, has once more proved the truth of the homely old saying that "the longest way round is the shortest way home," and of the useful maxim that "the most obvious course is not always the speediest or the safest."

SNAILS AND SLUGS.

By B. B. Woodward, British Museum.

DISMISSING for the moment all early prejudice against the family to which it belongs, let us begin by scrutinising the exterior aspect of that full-grown specimen (Fig. 1) of the Common Garden Snail (*Helix aspersa*), which is going over the ground at the top of its speed *en route* for the cabbage-bed. On picking it up one naturally observes that it, roughly speaking, consists of two parts—body and shell. The shell (Fig. 2), concerning which we shall have more to say as we go on, is a familiar object to all; it is strong, light, translucent when the body has been removed, and prettily marked with streaks and zigzags of brown and yellow, varying in different individuals both in tint and details of pattern. The "lip," or edge of the aperture, is slightly reflected, thus giving strength to this, the weakest part of the shell, which elsewhere, owing to its spherical build, will submit to considerable pressure before yielding. Gradually, as we have been speaking, the inmate has recovered

from his surprise at his novel situation, and with horns extended to their uttermost is vainly seeking some resting-place for the sole of his foot, permitting us to see that, while the skin of the upper part of the body is covered with closely-

Fig. 1.—The Common Garden Snail (*Helix aspersa*).

set wrinkles, the under surface is perfectly smooth and pliant, enabling the creature to make use of it as a sucker when climbing up the plants on which it feeds. This foot is composed of strong muscular fibres interlacing one another, and by the successive motion of its parts the animal is able to glide slowly along.

It is an interesting, not to say pretty, sight to watch the under surface of the foot either of a slug, or snail, in motion, and one which may readily be witnessed by inducing the creature to crawl on a piece of clear glass. A hollow glass cylinder, such as the chimney of a lamp, is preferable to a flat sheet, as affording greater facilities for close inspection and more ready handling. Having placed the slug, or snail, inside the tube, wait till it has got hold with its sucker-like foot, and then turn the glass round so as to bring the under side into view. So long as the animal remains at rest there is nothing in particular to attract one's attention; but the moment the creature begins to move a wonderful change takes place. The first impression is that there must be a hollow channel along the centre of the foot through which a foaming torrent is rushing pell-mell from the tail towards the head. Such, it is scarcely necessary to add, is not the case, and the torrential appearance is solely an optical illusion, due to the successive action of the surface of the muscular foot in propelling the animal forward. To understand the nature of this movement clearly, take the case of a caterpillar when crawling. First the hinder portion of the body is drawn up, forming an arch, then the feet in front of the arch are successively raised and those behind set down, causing the arch to move forward towards the head, though the parts of the body maintain the same relative position. By the time that the first loop, or "wave," in the caterpillar's body has reached its head, which is at once stretched forward, another "wave" has commenced at the tail; and so on. Now, the motion in a snail's foot is just the same, only the "waves" do not affect the whole body, as they do in the caterpillar, and they follow each other so quickly as to give rise to the appearance of flowing liquid. The margins of the foot do not participate in this motion, but have a gentle, lateral, undulating movement of their own. This motion of the muscular fibres of the foot is under the control of the animal so far as starting and stopping are concerned; but the actual motion itself appears to be automatic, and comparable to that of a locomotive engine, where the driver turns the steam on or off, leaving the actual work to the mechanism itself.

Fig. 2.—Shell of the Common Garden Snail (*Helix aspersa*), showing the Reflected Lip.

Reverting again to the upper surface of the snail's body, we notice the thick, tough, wrinkled skin, which is composed of transverse and longitudinal muscular fibres unsupported by any internal framework or skeleton, thus allowing the mollusc to vary its shape and expand or contract at will. Moreover, we see that this dermal envelope is kept constantly moist by the slimy mucous matter that renders these creatures unpleasant to the touch. The glands that secrete the slime are buried amongst the muscular fibres of the skin; but there is also a large one within the body; and an astonishing quantity of viscid slime can on occasion be poured out by these united glands.

As the slug or snail crawls along it leaves behind it a little of this mucous stuff, which, when dry, forms that glistening film on the wall or ground, known to us as its "trail" or "war-path." Certain of the slugs make another use of this tenacious material, for, taking advantage of its cohesion and

the rapidity with which it hardens, they will lower themselves by a fine thread of it off a tree or bush on to the ground. One species, indeed (*Limax marginatus*), can even re-ascend the gelatinous filament, a feat which, in its arboreal life, must often stand it in good stead. As the object of our inquiry has drawn in his horns, we must, if we would learn anything about them, follow whither they have retreated; more especially since, aided by the set of muscles that are attached to the interior of the shell and pass down into the foot, their owner has retired into his habitation, positively declining to be further interviewed.

Having killed it in the most instantaneous, and therefore least painful, manner—namely, by immersing it in boiling water, with a liberal allowance of table-salt—the animal can then be carefully extracted, periwinkle-wise, from its shell, and a more perfect examination of its structure instituted.

The difference between that portion of the creature habitually protected by the shell and the part exposed when in motion, is the first thing that strikes the eye, the skin covering the former being as thin and smooth as the latter is thick and wrinkled. The delicate membranous portion exposed to view by the removal of the shell is technically known as the *mantle*, and plays an all-important part in the snail's anatomy, as it is the shell-forming organ. Where the "mantle" is united to the tough skin of the foot, it becomes greatly swollen and forms a sort of collar, the edge of which may be seen curling round the reflected "lip" of the shell when the snail is crawling along.

The extension of the shell as its tenant grows is entirely effected by this swollen margin of the mantle, which carries the pigment cells, or glands, that secrete the colouring matter forming bands or patterns on the shell. The rest of the mantle is devoid of pigment glands, and merely deposits layers of shelly matter on the interior, thickening and strengthening the habitation. In the same way injuries to the shell are repaired. If only the mouth of the shell be broken the fractured portion is restored with all its proper colours and markings by the collar of the mantle; but if a portion of the spire be destroyed, the breach is closed by opaque colourless matter deposited by the other parts of the mantle.

The shell so formed is built up of layers of animal matter strengthened by the deposition of calcareous earthy matter which the snail derives mainly from plants; these in their turn obtain it from the soil; whence naturally it follows that snails are more abundant in limestone districts. The outermost or first layer, called the 'epidermis,' is of animal matter, and is endowed with life, but not sensation. It protects the shell from the influence of the weather, but soon fades and disappears after the death of the animal. This two-fold

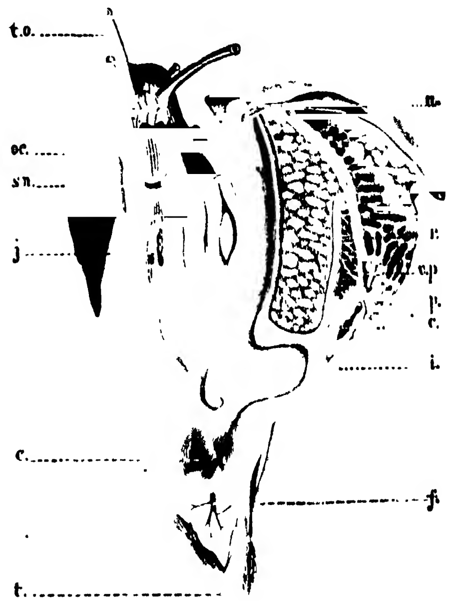


Fig. 3.—Diagram showing the Principal Points in the Anatomy of the Common Garden Snail.

(t o) Ocular Tentacles; (o e) Œsophagus; (s n) Cerebral Ganglion; (j) Gizzard; (s) Stomach; (l) Liver; (l) Biliary ducts; (i) Intestines; (a) Anus; (r) Kidney; (c p) Pulmonary ' cm; (p) Pulmonary Organ; (c) Heart

nature of the shell may be verified by placing a portion in water and adding a little acid, when the lime will be dissolved away, and nothing but the cellular membrane, in which the lime was deposited, left; or a piece of shell may be boiled in caustic soda to remove the organic matter, and then the inorganic lime will be left behind. Each layer of the shell was really, some maintain, once a portion of the mantle itself, which became calcified, that is, hardened with carbonate of lime, and was then thrown off to unite with those previously formed. Prof. Huxley, however, believes that shell-growth is not a case of *conversion*, but one of *excretion*, and that the shell is built up of successive excretions of membranous laminæ, in which granules of carbonate of lime are deposited, these granules gradually increasing in size, by the addition of fresh calcareous matter, till they almost touch, displacing the membranous matter and forcing it to assume a cell-like structure.

Whichever theory be adopted as the correct one, the result remains the same, and layer by layer a strong, light structure is built up, into which the creature can retire at pleasure, or retreat for protection from its numerous foes. In the young mollusc the shell is very thin and transparent, and the edge of the mouth shows none of that thickened and reflected rim characteristic of the adult individual.

On the right side of the body, under the collar of the mantle, is the opening which leads into the "pulmonary" or "breathing cavity," where the nearly colourless blood is exposed to the purification of the air in countless small vessels that ramify over the roof of the chamber. The floor of the cavity is formed by the diaphragm or thin muscular membrane which separates the respiratory apparatus from the rest of the viscera, and at the same time performs the office of bellows, alternately drawing the air in and driving it out. Most water-dwelling molluscs have a similar organ of respiration; but in their case the purification of the blood is effected by beautiful plume-like gills. On laying open the visceral cavity from the head along the back towards the anterior extremity, an intricacy of internal organisation is disclosed that will assuredly surprise any one seeing it for the first time (Fig. 3). In the first place, let us notice the digestive apparatus. Commencing with the mouth, which is placed on the under-side of the head, we find, in the first place, a kind of upper jaw consisting of a broad horny plate, with a very sharp, curved lower edge, and opposed to this is the tongue, armed with recurved silicious spines, or "teeth," as they are more commonly called. These teeth are set in a muscular membrane and point towards the back of the mouth; they are translucent, glossy, of various shapes, and set in rows forming different patterns, each genus, and even species, of snail possessing its own peculiar arrangement, shape, and number of teeth. This 'tongue' (*odontophore*), or 'lingual ribbon,' (Fig. 4) as it is variously termed, serves as a sort of rasp whereby, with the aid of the horny jaw, the toughest vegetable fibres or animal tissues can speedily be abraded. In the common Whelk the lingual ribbon is very long and narrow, and is employed by the animal to perforate the shells of its bivalve brethren. Through the breach thus effected the unlucky victim is devoured piecemeal.

In the snail before us, and in the slugs, the teeth are very nearly all of a size, and set so closely together as to give the tongue, when viewed only with a pocket-lens, the appearance of being finely marked with transverse striæ; if, however, it be properly prepared and placed under the microscope it reminds one rather of some marvellous piece of tesselated pavement. There are 135 rows of these teeth in the odontophore of the Common Garden Snail (*Helix aspersa*), and 105 teeth in each row, giving a total of 14,175 teeth in the whole tongue; but this is surpassed in the largest British land snail (*H. pomatia*), where the total is 21,140, disposed in 140 rows of 151 each; whilst in one of the slugs (*Limax cinereus*) this number is swollen to 28,800, placed in 160 rows of 180 each! As the teeth in the front wear away their place is supplied by the next in order, fresh teeth forming at the back, to be eventually used in their turn. Behind the mouth, which is amply supplied with salivary-glands, we find the œsophagus, which leads down to the stomach, whence the intestinal canal arises, and coming back again towards the head along the right side of the body, passes through the folds of the liver, terminating just within the respiratory orifice. The renovated blood is brought from the pulmonary cavity by a large vein to the heart, which consists of a single auricle and ventricle, whence it is pumped through the body again. The nervous system consists of three ganglia, or nerve-centres, connected with one another by nervous cords. The principal one, or, "cerebral ganglion," encircles the alimentary canal just behind the œsophagus. From it proceed the nerves that pass to the tentacles, or horns, and to the mouth. The other two supply the foot, viscera, and respiratory organ. In this respect, therefore, the snail offers a great contrast to the insects, in which there is a nerve-centre for every segment of the body.

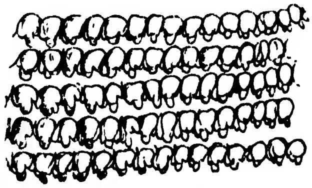


Fig. 4.—Portion of the Odontophore of *Helix hortensis*.

The extremities of the upper and longer pair of "horns" terminate in a round knob surmounted by a black speck—the eye. This, though not so perfect as in the cuttle-fish, is nevertheless sufficiently developed to enable its owner to distinguish though vaguely the nature of surrounding objects. The method by which these eye-stalks are drawn into the visceral cavity when danger is apprehended, and thrust out again when the cause of alarm has passed away, is worthy of attention.

Each of these tentacles (Fig. 5) is a hollow flexible tube, whose muscular walls are composed of circular fibres. The special muscle by means of which this tentacle can be drawn in is attached to the base of the eye at the extremity, and, passing down the tube, joins the general muscular mass of the foot. It is accompanied by the optic nerve, which likewise passes along the tube, connecting the eye with the cerebral ganglion. When the muscle contracts, the tip of the "horn" is drawn inwards followed gradually by the remaining portion, just as, to quote a well-known example, the finger of a glove can be pulled in and completely inverted. Its protrusion, on the other hand, is effected by the action of the muscles that compose the tubular wall of the tentacle itself. By concentrating the rays of the sun or a lamp on the extended tentacles of a living snail and looking at them through a magnifying glass, the extension and retraction of these organs can easily be studied, the action of the muscles noted, and the trouble of dissection obviated. The inferior and shorter pair of tentacles undergo inversion in the same way as the larger pair; but they are destitute of eyes, serving, apparently, merely as organs of touch, in which they are supplemented by the sensitive skin of the creeping disc and body. Where the sense of smell resides in a snail is not yet determined; but that they do possess this faculty we have abundant evidence to prove. Slugs, too, are attracted by offensive odours, and many marine mollusca, like the Whelk, may be caught by animal baits, especially if these be at all "high."

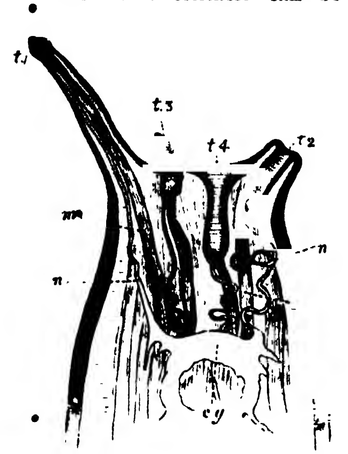


Fig. 5.--Diagram of the Structure of the Tentacles.

(cg) Cerebral Ganglion; (n, n) Nerves; (m, m) Retractor Muscles; (t 1—4) Tentacles

The means of recognising sound is provided by vesicles which are situated at the bases of the tentacles. They consist of simple cavities containing a fluid, in which the 'otoliths' (or ear-stones) are suspended.

The faculty of taste, if possessed at all, must be very faint indeed, judging from the structure of the mouth and tongue. Nevertheless, a certain amount of discernment appears to be exercised in their choice of diet, since they exhibit a preference for plants of the pea and cabbage order, and will emigrate or fast sooner than touch the white mustard plant. Some, again, seem to prefer animal food, especially when "tainted," to vegetable diet.

On turning over an old flower-pot in a damp corner of the garden, one sometimes meets with a number of small round bodies, soft, semi-transparent, and about the size of small peas. These are the snail's eggs. Their only protection is a tough albuminous envelope; whilst some of the foreign species *Bulimus*, a genus closely allied to the *Helices*, lay eggs as large as a pigeon's and, like them, enclosed in a firm, white, calcareous shell (Fig. 6). Some three or four species of the Helices are viviparous, the young snails passing through the early stages of their development within the body of the parent. None of these, however, are British. The eggs of the garden snail, in number about 100, are usually laid in the summer; the young snails appear at the end of from fifteen to twenty days, and by the autumn have attained about a third of their full size. Each considerable increment of the shell is performed underground, whither they retire for the purpose, and bury themselves head downwards.

Fig 6.—Bulimus and Egg

During the winter they hybernate, burying themselves in this case head upwards, or they will retire to sheltered nooks, in either case closing the mouth

of the shell with a hardened layer of mucus, or "lime," known as the *epiphragm.** On the return of the warm weather they burst from their confinement, and complete their growth within the end of their first year. Their lives, however, are short, and they do not, in the natural state, seem often to survive the second winter; but in confinement they will attain the advanced age of six, or even eight. Perhaps one of the most interesting examples of long-endured compulsory hybernation was that undergone by one of the Desert Snails (*Helix desertorum*), from Egypt, who had been stuck on a tablet in the British Museum in March, 1846, and was found to be still alive in March, 1850.

Fig. 7.—Monstrosity of the Common Garden Snail.

Instances of malformation in the shell of our friend are tolerably common, snails, like other mortals, being liable to accidents. Cases of monstrosity, such as reversed or left-handed varieties, where the shell has been wound the wrong way, have occasionally been met with, in which case the relative positions of the internal organs are reversed too; but the most extraordinary specimen of abnormal growth is the curious cornucopia-like variety now in the British Museum, a distortion towards which the malformation we figure (Fig. 7) presents but a faint approximation.

The capability of reproducing lost or damaged portions of the body is another characteristic of the snail, and one which it possesses in common with many other creatures both higher and lower than itself in the zoological scale. The experiments of the Abbé Spallanzani show that the tentacles, if cut off, can be reproduced, eyes and all, at the end of about two months. Even the removal of the whole head seems but to cause them temporary inconvenience, as it is entirely and perfectly reproduced after a little time, during which the mollusc keeps close within his shell.

The foregoing remarks on the Common Garden Snail apply, with but slight exceptions, to all his intimate relations. Prominent amongst these is the handsome Yellow-banded Snail so common on all hedgerows, and by far the most gaudy of the British *Helices*. There are two varieties by some considered as distinct species of this mollusc. In one (*H. hortensis*), the lip of the shell is white; in the other (*H. nemoralis*), brown. Of these, the white-lipped variety appears generally to be the smaller.

* The Edible Snail (*Helix pomatia*) derives its name from the very thick and solid "epiphragm" it forms, *poma* signifying a "lid."

The bands with which this shell is striped vary in number from one to five, and though generally of a chocolate-brown colour sometimes appear quite colourless on the yellow shell.

Then there is (Fig. 8) the large Roman or Edible Snail (*H. pomatia*), imported into this country by the Romans. It is renowned both as a delicacy, and, on account of its reputed virtues, as a remedy in cases of consumption, which, it is said, has in several instances been entirely cured by a regimen of the mucilage from these snails. On the Continent the Roman Snail is considered a great delicacy; but the Garden and Yellow-banded Snails are the kinds more commonly eaten. A snail feast is held annually in the South of France on Ash Wednesday, when large numbers of them are consumed. An analogous custom is said to prevail in our own country amongst the operatives of Lancashire, and at Newcastle. The Roman Snail is very local in England, and confined to the southern portion of the island. It is very plentiful at Reigate, and after a smart shower may be seen in abundance on the steep chalk face north of the town. Another local snail is the prettily-banded *H. Pisana*, only to be found in Cornwall, South Wales, south-east of Ireland, and Jersey; whereas in Spain and Southern France it is common, so that it would be interesting to know how it came to these isolated spots in England, more especially as it is unknown in Northern France.

In direct contrast with the scarcity of this last species is the abundance of such forms as the Kentish Snail (*H. cantiana*), and the pretty little *Helices*, white banded with black (*H. virgata*), that with two or three others are so plentifully scattered over the grassy slopes of the South Downs. These last are alleged to be the cause of the superior flavour of South Down mutton, as the sheep must infallibly consume them in large quantities when cropping the short grass. Altogether in the British Isles there are some thirty species (if we include their first cousins the *Zonites*) closely allied to our friend the Common Garden Snail.

Intermediate between the *Helices* and the slugs comes a curious little genus, *Vitrina*, represented in this country by a single species that unites in itself characteristics typical of its relations, so to speak, on either side. Thus it possesses the shield and

conspicuous respiratory orifice of the slug along with the whorled shell of the snail. It is a very pretty little mollusc, with a thin, transparent, glossy that is more or less soft when the animal

Fig. 8.—The Roman or Edible Snail (*Helix pomatia*).

is alive, but becomes brittle after its death. It dwells principally amongst moss and dead leaves, and though professedly a vegetarian, likes nothing better than a good meal of an animal nature.

Slugs, to which we next come, present, as everybody knows, one very marked difference to the snails in that they are devoid of any external shell; nevertheless, the majority of them possess a small shell, or the rudiments of it, concealed beneath the oval prominence on the back—the mantle, frequently termed the "shield."

The anatomical structure of these homeless molluscs closely approximates to that of their householder brethren; but in the one case, as we have already seen, the viscera are separate from the foot, and are carried coiled up on the back and enclosed in a shell-secreting mantle; in the other, these organs lie along the back under the same tough muscular skin that clothes the foot, the mantle reduced to a mere patch on the back, secreting calcareous matter on the inner and not the outer surface. It is significant that in the Helices, too, the first deposition of shell probably commences by the formation of calcareous granules *within* the substance of the mantle. The want of a capacious shell as a protecting stronghold in times of danger is nevertheless compensated to the slug in the additional facility with which, freed from such encumbrance, it can contract, and retreat into cracks and crannies whither it would be impossible for the snail to creep. By way of proving the rule that slugs have no external shell two members of the tribe carry a small, ear-shaped, calcareous shell stuck on the posterior extremity of the body, where it is situated nearly over the respiratory orifice. Why the mantle, with the attendant breathing apparatus and shell, should be posted so far back in this genus (*Testacella*), instead of being situated well forward, as in the rest of their tribe, is not at first apparent. When, however, the habits and mode of life of these two, so to speak, eccentric individuals are taken into consideration this peculiarity of structure is no longer mysterious. The *Testacella* are carnivorous, and feed on earth-worms, which they fearlessly pursue through the dark and tortuous passages of their underground burrows, and which they will devour even if many times their own length. Now, were the respiratory orifice placed as in the rest of their race it would be liable to become choked up with particles of earth falling from the sides of the worm's burrow. Nor would a protecting shell in such a position be of the smallest use, as it would catch against everything, if it did not positively preclude the animal altogether from entering the narrow passage. Moreover, were the burrow a narrow one, and the slug full sized, the animal would inevitably be suffocated because no air could get to the pulmonary cavity, since the elastic, slimy body would completely block the way. Placed as we find them, the slug is enabled to make full use of these organs; it can breathe freely, the orifice being quite in the rear; it is in no danger of being choked by earth, for the shell guards the entrance of the cavity and serves, in addition, as a buckler to shield the creature from hostile attacks in that quarter, without hindering its progress. In other words, to put the matter in its proper light, those *Testacellæ* which were the better able to breathe in the narrow track, and were best protected, were also the better qualified to pursue their prey, and therefore to live and perpetuate their species.

The peculiar food of the *Testacellæ* has likewise engendered special modifications of structure in its mouth and tongue. The former is exceedingly wide and capacious, the corners, when it is at rest, protruding till they resemble a third pair of tentacles.

The tongue is correspondingly large and wide, with about fifty transverse rows of teeth (Fig. 9). In each row are fifty-one slender teeth barbed at the points, which, as in other molluscs, are directed towards the back of the mouth, aiding in passing the food on to the gullet, so that the more the worm struggles to free itself the more surely does it become engulfed.

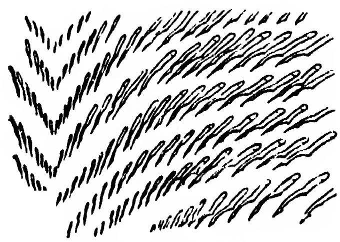


Fig. 9.—Part of Odontophore of *Testacella haliotoides.*

The *Testacellæ* are linked to Vitrina by a Continental genus (*Daudebardia*), in which there is no shield; but the pulmonary sac is situated at the posterior extremity of the body, and covered by a little spiral Vitrina-like shell. On the other hand, it is connected with the slugs proper by another Continental genus (*Parmacella*), where the shield is in the centre of the body, concealing a small shell within its folds.

The remainder of the slug family are too well known to need more than a passing word; every one has, at one time or another, met the magnificent Black Slug (*Arion ater*) taking his walks abroad in the cool damp of an autumn evening; or has seen the large Ash-gray Slug (*Limax cinereus*), with his black stripes and other decorations, who, in company with the Yellow Slug (*L. flavus*), haunts the dust-bin and cellar, feeding on the refuse matter from the table. The latter has gained the reputation of being able to clean bones well, and of exhibiting a liking for cold potatoes.

Who, too, that keeps a garden has not had cause to mourn the depredations of the smaller but more destructive Grey Slug (*Limax agrestis*), a species which is, unfortunately, very prolific, and brings up several families in the year?

To trace the garden snail's relations in the opposite direction away from the slugs, would be to attempt to compress the materials of a manual into a few pages. The kith and kin of our *Helix* may be found figured and described in many a work, or sought for practically in the damp spots in which all snails love to dwell. For moisture is to them a *sine quâ non*, and the amount of water they will take into their systems is astonishing. Experiments made in this direction on *Helix pomatia* tend to show that the quantity of water they can absorb when in a healthy state exceeds in weight that of the animal itself, and appears to be taken thoroughly into the system.

The genus *Helix* is an exceedingly large one, and comprises nearly 2,000 known species, distributed all over the world, extending northwards as far as the limit of trees, and southwards to Tierra del Fuego. The examples common in Britain are spread largely over the continent of Europe, and many of them extend into Northern Africa; whilst some few are known to occur as far East as Siberia, and others are found even in the United States.

The Yellow-banded Snail with the brown lip has been seen even in Greenland, in company with the Grey Slug (*Limax agrestis*).

Doubtless, with the increased facilities of intercommunication between different countries, the present distribution is gradually changing. Species accidentally introduced into this country, or imported from it to others, will, if they meet with conditions suitable to their development, in process of time become acclimatised.

In this way *Testacella Maugei* was imported into England in 1829 or 1830, along with plants, to some nursery grounds near Bristol, whence it has spread to Devizes. Of the introduction of *Helix pomatia* we have already spoken, and *Helix pisana* is probably another intruder. Our exports are more numerous, and appear to have gone almost exclusively to the United States. Statistics show the successful trans-shipment to that country of three species of slugs (*Arion hortensis*, *Limax agrestis*, and *L. flavus*), and two snails (*Zonites cellarius* and *Z. radiatulas*). The last-named went over in some casks.

It is also probable that *Helix fusca* was transported into Northern France from this country about the beginning of this century, as it was not observed there till 1838, and then only in the part nearest to England, the first specimens recorded being found in the neighbourhood of Boulogne.

Somewhat more than 200 species of Helix and several slugs are known to us by their shells as occurring in the fossil state. With one exception, none of these are older than the Eocene * period; this exception is a much mutilated shell of *Helix* from the Gault of Folkestone, preserved in the British Museum.

Land snails, nevertheless, made their appearance at a much earlier date in the world's history, for the Coal-measures of Nova Scotia have yielded specimens of a species of *Zonites* (or closely allied

* See Frontispiece to "Science for All," Vol. I.

form) as well as examples of a shell generically undistinguishable from the "Chrysalis Shells" (*Pupa*) of to-day.

A great number of our living Helices are found fossil in the upper Tertiary beds, such as the Pleistocene deposits in Essex, associated with forms now living on the Continent, but which have become extinct in Britain. Curiously enough, though the Tree-snail (*Helix arbustorum*) and the Yellow-banded Snail (*H. nemoralis*), along with their smaller brethren, are rather common in these Fresh-water Marls, the Garden-Snail (*H. aspersa*) is, on the contrary, conspicuous by its all but total absence, only a single example having been recorded of earlier date than that of the Roman occupation.

Numerous and prolific as slugs and snails are, their numbers are largely held in check by many powerful foes, leaving man entirely out of the question. Birds devour large quantities of them. Ducks especially thrive on them, and are capital scavengers of an infested crop, when the plants are not too young.

Every one is familiar with the stone altar on which the thrush sacrifices his victims, and has seen how, when he has found a choice snail, he flies off with it to the sheltered nook where this stone lies, and raising his beak aloft brings the shell down with all his force on the stone, blow succeeding blow, till the fortress is battered in, and the inmate secured. This process being repeated with each fresh capture, the ground around the stone is soon strewn with fragments of shell. The lapwing has a very similar habit, and blackbirds, rooks, and starlings all enjoy a snail feast, swallowing the smaller kinds, shell and all. The hedgehog also helps to thin their ranks; whilst frogs and toads, together with slow-worms, consider slugs most luscious morsels, and treat them accordingly.

Several insects, including the well-known glow-worm, deposit their eggs in the snail's body, the grubs, when hatched, feeding on and finally destroying their host. Whilst, to complete the list, comes a fungus that attacks the eggs of the Grey Slug (*Limax agrestis*), sometimes even before they are extruded from the body of the parent. Altogether apart from these internal plagues is the curious little being (*Philodromus limacum*), which especially infests some of the slugs. These minute acari (or mites), for such they are, appear to reside principally in the breathing cavity of the mollusc, though what they do there, or whether they penetrate farther still, has not yet been satisfactorily determined. At intervals they issue forth, and may be seen running races with impunity all over the slippery body of their apparently unconscious host, the peculiar structure of their feet enabling them to keep their footing perfectly on the surface of the slimy mucus. To safely capture one alive for microscopic purposes is by no means easy, for the least rough handling destroys them, whilst they laugh at water, and elude even the tenacious grasp of Canada balsam.

A WATER-WHEEL.

By William Dundas Scott-Moncrieff, C.E.

In two previous papers, the relationships were explained which exist between the two forms of force known as "power" and "work." The one in scientific language is called potential, and the other kinetic energy, and illustrations were given from among the forces of nature, as well as from the appliances of the arts, to show how the one is convertible into the other (Vol. II., pp. 97, 225).

In every kind of applied science the element of saving is of the utmost importance, and is an essential feature of all true progress. What I now wish to explain is how saving can be conducted in a scientific manner, and to point out how it has been carried out in familiar appliances of the mechanical engineer.

As in the common affairs of life, so in those of science, saving may be classed under two great divisions: the first of these having reference to the accumulation, and the second to the art of using, our resources in a wise and economical manner. Our resources having been accumulated, and the purpose we propose to ourselves in using them having been fixed upon, it will be found that they invariably include two objects that are universally desirable, viz., the saving of time and the saving of labour, both of which include the saving of money as well. These are the great stimulating influences which urge us in our endeavours to obtain a substitute for the labour of the body; and in making use of the supplies of energy which are

discovered in nature, it will be found that true economy in the scientific sense consists in avoiding, first, waste of force-producing materials, and, second, waste of force itself.

For our present purpose, then, we must divide materials into two great groups: viz., those that are force-producers, and those that are not. The force-producing group will supply amply sufficient to engage our attention.

In the case of the materials which produce force, we must look at them in one or other of two distinct points of view, that is, either upon their real or their comparative value. If we mix up these two, we find ourselves at once confused as to what the meaning of the word value really is. In order to show the difference between the real and the comparative value of force-producing materials we cannot do better than use a common illustration of every-day life. We will find one in the case of a coin the value of which is continually changing, while the number of smaller coins which go to make it up remains constantly the same. Now, of the value of a coin such as a sovereign every man must be the best judge for himself as to whether or not it is worth his while to exchange it for something else, but of the number of pennies in a sovereign no one can be in doubt, and it is either through ignorance or carelessness that anything short of a certain number is obtained in exchange for it. Now, looking at our force-producing materials from the point of view of their comparative value, every one, as in the case of the sovereign, must be the best judge of this for themselves. This value depends upon the valuable considerations which must be given in order to obtain the materials and also upon the advantages which may accrue from their use: the balance between these, as it happens to be on the right or wrong side, becomes the standard of their comparative value. But something more than a knowledge of this balance is necessary in a scientific sense. Just as it would be impossible for economy to exist amongst business men who were ignorant of how many pennies go to make up a sovereign, so it is necessary to know something of the value of the materials in terms of an exact unit of measurement. The same reasoning holds good with regard to the employment of all the forces supplied by nature, and it is requisite, in order to use them nicely, that we should know exactly what they are worth in terms of some exact unit and standard measurement. This knowledge teaches us how to economise our force-producing materials by informing us as to their theoretical or total value. In other words, it informs us how to employ power and work, or potential and kinetic energy, economically.

Turning our thoughts now to our supplies of force and force-producing materials, we must be able to arrange them in such a way as to apply the principle of saving in a manner consistent with the peculiarities of each. In order to do this it will be well to subdivide our resources into two groups: first, those that can be obtained direct from nature, as in the case of wind-mills and water-mills; and second, those that require to be converted from one form of energy to another before they become available, such as the combustion of fuel and the production of electricity by means of the voltaic battery. The comparative values of these two groups may be referred to a standard that rises or falls with the amount of labour which is necessary in order to obtain them. The first, which may be had for the taking, involves the construction of the necessary machinery and the labour required either in conveying the raw materials and the finished products to and from the source of power—a serious item in the early days of the cotton trade—or in conveying the force-producing material to the industrial centre, as in the case of certain aqueducts.* The comparative value of the other group depends upon the scarcity or plentifulness of the materials from which it is supplied. If coal, which is at present, in our own country and many others, the principal force-producing material, were as scarce as the metals necessary for the production of voltaic electricity, and these metals as plentiful as coal, and the acid required for the process as plentiful as oxygen, then the comparative value of the two sets of materials would be reversed, and, no doubt, electricity would take the place of heat as the great motive power of the world. As matters stand, it is chiefly to the heat-producing materials we must look for providing the means of saving time and labour upon a large scale; but before turning to this branch of the subject, which will afford ample materials for another paper, it will be well to finish what has to be said about the first group of our resources which are derived directly from nature.

* An interesting illustration of the employment of water-power on a large scale is to be found in the town of Greenock, where a moorland lake is made available for the force necessary for carrying on a variety of industries. In this case the enterprise referred to helped greatly in developing the trade of the town, but has taken a secondary place since the rival forces of the steam-engine have been proved to be an advantageous substitute.

In the case of the great source of power to be discovered in the operations of the sun in raising water to lofty elevations above the level of the sea, through the medium of the clouds and the rain-fall, the real power value depends upon the difference between the height at which the water is stored and the height at which it is used. If this is doubled, the amount of force is approximately doubled, and so for every increase or diminution proportionally. This being the case, it becomes evidently the business of practical science to store the water at the highest possible level and use it at the lowest. The number of force units stored up in the form of potential energy in the elevated water are simply the equivalent of those that would be necessary to place it in that position. If we take a weight of 33,000 lbs. of water and raise it to a height of 100 feet, and then suppose it to descend in one minute, an amount of force ought to be theoretically available which is the equivalent of 33,000 lbs. multiplied by 100 feet, or the power of 100 horses of standard strength working during the period of one minute. If we multiply the height by 10, and thus raise the water to a height of 1,000 feet, instead of 100, then we get an equivalent to the work of 1,000 horses working during the same period. Now, although there is an evident advantage in making use of a difference between the height of the water and the level of a mill when in one case it is ten times higher, and is theoretically capable of doing approximately ten times the work of the other, it is equally clear that some apparatus must be devised in order to take advantage of the difference. With water-power it is not possible to have a wheel of such a vertical diameter that a very high elevation can be taken advantage of in practice by the fluid following its revolution during the whole of the descent. Even if a wheel were constructed that could span the top and bottom of a fall of say 100 feet, even then the water would lose a considerable amount of its full theoretical force value. It is also clear that in practice it would not be possible to take advantage of the potential energy of water falling from a great height upon an apparatus placed at the lowest possible level, because the kinetic energy of the descending fluid would break the strongest mechanism to pieces. Some method of utilising the full measure of the natural forces referred to was absolutely necessary in order to make an economical use of them, and the manner in which this has been accomplished will form a fitting conclusion to the present paper.

The inventor, as M. Taine remarks, is the true thinker. It is a mistake to suppose that his discoveries are inspirations. Years of thought are often condensed within the compass of a single idea that is capable of being conveyed to the minds of others in a few moments' conversation. In the improvement of the water-wheel many minds have been at work for many years, but, roughly speaking, we cannot be very far wrong in estimating the reasoning which led up to several of the most important inventions in something like the manner following. The first difficulty that must have occurred to an inventor impressed with the faultiness of the old water-wheel was, no doubt, the obstacles that lay in the way of connecting the top and the bottom of the fall. But it has long been well known that the pressure of water in a pipe is proportional to its height or head, and that when it is confined in this way the total pressure at the bottom would be an available form of potential energy if an apparatus could be devised to take advantage of it. Once introduce an apparatus, such as a pipe, for confining the water, and the height at which it would be possible to make use of it would only be limited by the strength of the tube and of the machine which took the place of the common water-wheel. The substituted apparatus would be required to fulfil the functions of a vertical wheel, but in such a manner as to convert a much greater amount of potential energy into work, in proportion to its size. Now as the amount of work given out during this process would increase or diminish directly as the quantity of water delivered, this must have forced the mind of the inventor to the conclusion that the new wheel must revolve at immense velocity in order to admit of a great discharge. Instead of a slowly moving machine like a low-pressure steam-engine, a high-pressure apparatus would require to be substituted, in which great velocity took the place of a large diameter. In carrying out the new plan, the relationships between the height of the fall and the speed of the wheel required to be reversed. In breast and over-shot water-wheels the speed of the periphery decreased with the head of the water, and the apparatus depended more upon its great radius than its speed for the development of work, as the following table will show. The first column gives the height of the fall in feet, and the second the velocity of the rim of the revolving wheel, based upon what was found to be best when water was a more common source of power than it is at present.

Fall of water in feet.	Velocity of periphery of wheel in feet per second.
5 feet	6·6 feet.
20 „	5·8 „
40 „	4·2 „
50 „	3·4 „

At first sight it might appear that the lower fall was the more economical of the two, because in the case of the water descending from a height of 5 feet the periphery of a well-proportioned wheel moved at the rate of 6·6 feet per second, while with a height of 50 feet it moved only at the rate of 3·4 feet in the same time. If the difference of the diameter, however, is taken into account, it will be found that for the same quantity of water the larger wheel develops much more work in proportion, and was therefore more economical. In the case of the small wheel the water works through a radius of 2·5 feet, and in the case of the large one through 25 feet, so that it ought to do ten times the work, or the full theoretical difference due to the difference of the falls; but as it moves at only half the speed it only does five times the work, and half of the theoretical value of the height of the water has therefore been lost. The old wheels had hitherto been classed under the following heads, and the figures opposite to them show the percentage of work which was obtained from them, the theoretical power available being 1·00:—

Under-shot (which includes the ancient apparatus of the floating mill, anchored in a running stream)	·35
Breast-wheel	·55
High-breast	·60
Over-shot wheel	·68

It will be seen from this table that the lowest on the list is the under-shot wheel, with a loss of 65 per cent. of the power supplied by nature, but by an ingenious invention, known as "Poncelet's Under-shot Water-wheel," the work available was raised to no less than 60 per cent., or a loss of only 40. As this was carried out on the same lines as the "Turbine," viz., by bringing the speed of the wheel into some reasonable proportion to the velocity of the water due to its head, it will be well to explain it. In the case of the over-shot wheel, with a fall of 50 feet, the theoretical velocity of the water due to that head is at the rate of 57 feet per second, but the velocity of the periphery of the large wheel in practice was only 3·4 feet in the same time, or only about one-sixteenth of the velocity. The large wheel was so arranged that each of the buckets had time to take a full load of water, and descend slowly with these in the course of its revolutions. It was in this way by no means a very wasteful machine, but its dimensions required to be enormous to take advantage of a large supply of water, and the potential energy of water moving at a high velocity was not in any way taken into account. The under-shot wheel was the apparatus that had hitherto taken advantage of the pressure of the water, due to its head moving at a velocity in some reasonable proportion to that which is due to the fall, to a greater extent than the over-shot wheel, which depended for the weight of the water falling slowly through a large diameter, or the breast-wheel, which combined the elements both of weight and pressure; we accordingly find that the ratio between the speed of the periphery of the under-shot wheel and the theoretical velocity of the water, instead of being as 1 to 16 in the case of the large over-shot, could be made as 0·57 to 1, or rather more than one-half instead of one-sixteenth. This being the case, Poncelet improved the arrangement of the under-shot wheel, so as to take advantage of this velocity, as shown in Fig. 1. Referring to the diagram, A is the water; B B B the buckets; C an obstruction placed in front of the wheel, so as to force the water through the channel D; and F a floor fitting the wheel accurately at G, and dipping suddenly at the point H, so as to allow the water to escape freely along the tail-race at K. By this arrangement the principle of the Turbine was to a certain extent anticipated, as the object was obtained of approximating the velocity of the periphery of the wheel to that of the water due to its head; and in the channel at D we have a step towards the introduction of the pipe or tube which is one of the essential features of the high-pressure wheel.*

The inventors of the "Turbine"—for there were many, among whom the names of Barker, Jonval, Thomson, and Fourneyron are distinguished—having set themselves the task of saving the waste of power, which in the case of certain kinds of wheels, as has been shown, amounted to as much as 65 per cent. of the total potential energy of the water, had first to arrange that the new apparatus should revolve at a velocity proportional to the height of the water, and not in an inverse ratio, as in the old wheels.

* Referring to the illustrations, it will be noticed that the shape of the buckets in Poncelet's wheel differs from those that had been previously employed in over-shot and breast-wheels, of which one or two types are shown. One of the most interesting of these is Fairbairn's ventilating bucket, which was designed to allow of the chamber being completely filled with water which the presence of air without a means of escaping from beneath the descending fluid had a tendency to prevent.

The most salient distinction between the older forms of water-wheels and that generally known as the Turbine, is to be found in the relative position of their shafts or axles. There was, and still is, an old kind of water-wheel constructed with blades like a vertical undershot, but placed horizontally and acted upon by a spout of water. These are called *rouets volants*, and are still used in the South of France, and in Algeria, but with the exception of these the broad distinction introduced with the Turbine was that their shafts were upright instead of horizontal.

Fig. 1

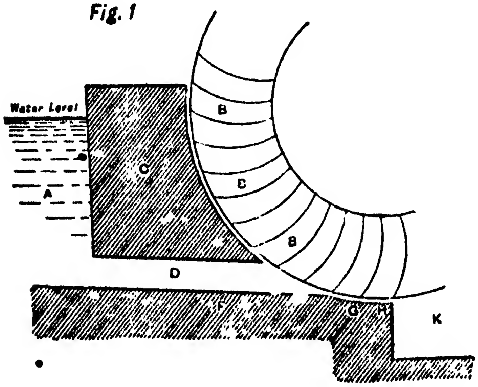


Fig. 2

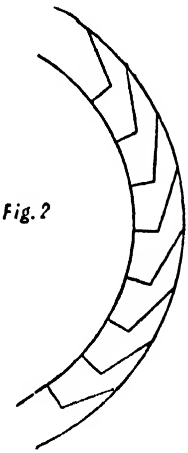


Fig. 3

Fig. 4

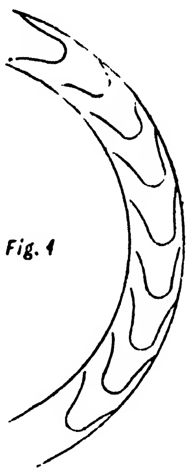


Fig 1.—Poncelet's Breast-Wheel; Figs. 2, 3, ordinary forms of two and three parts bucket; Fig. 4, Fairbairn's Ventilating Bucket

The first practical application of a water-motor in which one of the essential features is a pipe conveying the pressure due to the head of water to an apparatus rotating vertically, is attributed to Dr. Barker, whose invention came into notice in the seventeenth century. It is universally known as Barker's Mill, and although depending upon a mechanical principle that is only employed to a limited extent in the modern Turbine, it was really the progenitor of all the wheels with the distinctive peculiarity already referred to of an upright shaft. For a long time there seemed to be no reasonable way of accounting for its action. Its rotary motion arises from the pressure of the water acting on all the interior surfaces of the apparatus including that portion of the horizontal tube immediately opposite to the point at which the water escapes. As there is no corresponding pressure in that direction the water forces the tubular arms backwards, and if they are free to move they will turn round and perform any work that is adjusted to their power. Improvements were introduced by making the arms of the Barker mill of a curved form, and thus modified it became a very popular piece of mechanism, especially in France, where it found much favour. Another step in advance of the original was made by James Rumsey, who instead of bringing the water in at the top, an arrangement by which the apparatus required to be of great height, if the pressure of any considerable column of water was to be made use of, brought it in underneath. This made it possible for the first time to unite the top and bottom of a fall of water so as to utilise the pressure due to this height.

A description of the various forces that have to be calculated upon in the construction of a modern Turbine is beyond the scope of the present paper. It is enough to say that they are divided into one or two well-known classes. The success of the apparatus under high pressure led to the devising of methods for making it available for situations in which the fall was limited, and hence the name *low-pressure* Turbine, as opposed to the *high-pressure* wheels adapted for great heads of water. Another broad distinction exists between the wheel originally perfected by Jonval and Fourneyron and that which is known as the *vortex* wheel. In the former the water invariably entered at the centre, and communicated motion to the apparatus, escaping, as in the Barker mill, at the periphery. In the latter, which was the invention of Professor Thomson, of Belfast, and now of Glasgow, the water enters through suitably con-

structed passages at the rim, and escapes at the centre, giving the name of vortex from the peculiar whirling motion, which is characteristic of the invention.

Without going into further details, enough has been said to indicate how the problem of uniting the top and bottom of a fall of water has been solved. In describing the mechanism of the water-wheel, we have brought before the reader's notice one of the oldest and most familiar forms of apparatus for taking advantage of a natural store of potential energy, and in the improvements which have been introduced, there is an apt illustration of how saving, in a scientific sense, can be applied in the act of converting power into useful work. We have still to explain how other stores of energy, converted into work by more complicated processes, can be treated economically. This matter, however, as it belongs to a different division of the subject, will more appropriately form materials for another paper, than for treatment here.

THE CHEMISTRY OF A COLOUR BOX.

By Professor Barff, M.A. Cantab., etc.

It should be a matter of interest to those who use paints to know something of their composition, and I hope that, amongst the young persons who read this article, what is here written will increase that interest, and lead them, should they ever make art the chief employment of their lives, to learn the nature of the substances with which they work. Ignorance of the composition of pigments, and how they act upon one another when they are mixed, has been a fruitful source of injury to modern pictures, as colours have changed their tints, and some have almost altogether disappeared. What are called the "old Masters" knew far better than modern painters how they could use their colours, because they either made or prepared them themselves; and continental artists, who are usually students and earnest men, either acquire *themselves* the scientific knowledge necessary, or work under the instruction of those competent to advise them. There are some in this country who adopt a similar course, but they are only the few; the many are content to blunder on in the old way, and the consequences are lamentable, as can be seen in the pictures at the National Gallery and at South Kensington.

Although we are now chiefly concerned with the *chemistry* of pigments, it may be interesting to describe the way in which pure colours are manufactured and prepared for use. Messrs. Winsor and Newton have allowed me to inspect their large works at Kentish Town, London, and it is from information obtained there that I am enabled accurately to describe the way in which water colours are prepared. In this article we have to deal only with water colours. After the colouring material of the paint is made, it is carefully ground in water, and washed so as to remove dirt and all impurities; this operation of washing is in many cases often repeated. The mill-stones between which the grinding takes place are made of granite; they work on one another horizontally, and are fed from above; the scrapers, which remove the paint as it issues from between the stones at their edges, are made, in some cases, of the best steel, but where this metal might affect the colours injuriously ivory scrapers are used in the place of steel ones. When the paints are ground sufficiently fine, they are dried slowly, some completely, others being left in a pasty condition; they are then mixed with suitable quantities of gum, mucilage, and sugary matter; the mucilage is used to give toughness and to prevent the cakes from cracking. These materials are added in different proportions for different colours, some requiring more and some less mucilage. The mills in which the paints are ground are beautifully made, and are expensive, each costing over £200. Soft colours are prepared with a larger quantity of saccharine matter, and are put into little china vessels, or into metal tubes, similar to those used for oil colours; when contained in china vessels they are covered with tinfoil. These colours, when well made, retain their moisture for a very long time. The mixture intended for ordinary cakes is dried till it is sufficiently plastic; it is then rolled out to the required thickness and stamped into the cake form by a die. Cake colours should never be kept in a damp atmosphere or be shut up in air-tight boxes, as they absorb moisture and become soft.

We will now consider the reds first, then yellows, then greens, and lastly blues, whites, and browns, our space only admitting of the colours *generally* used being described.

"Vermilion."—This beautiful red paint, which is so very valuable to the artist, is always made in large quantities, some two or three manufacturers in this country having the speciality. It was formerly imported from China, and Chinese vermilion was considered to be the best. It is still obtained from that country, although English makers now produce an article equal, if not superior, to the Chinese. Vermilion is a sulphide of mercury, and is composed of two hundred parts, by weight, of mercury chemically united with thirty-two of sulphur. Sulphur and mercury unite directly at the ordinary temperature of the air, so that, if some mercury be put into a mortar and be rubbed up with some flowers of sulphur, the metallic lustre of the mercury and the yellow colour of the brimstone will disappear, and a grey powder, sulphide of mercury, will be left. If this be put into a hard glass tube, closed at one end, and be heated to a high temperature, the powder will be converted into vapour, and will pass up the tube and be deposited in the cooler part of it, above the flame. This operation is called sublimation, and the sulphide of mercury so treated is said to be sublimed. If the tube be broken, and the deposit taken out and examined, it will be found to be harder and blacker than the original grey sulphide, and it generally has somewhat of a metallic lustre. When rubbed for some time in a mortar its colour becomes red, and the change is more complete the longer it is rubbed, for the particles become more finely divided.

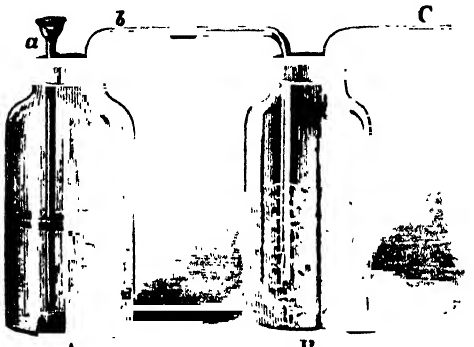


Fig. 1.—Apparatus for generating and drying Hydrogen.

Sulphide of mercury is found in nature; its colour is red; it varies in tint from a brick red to a bright vermilion, some pieces being sufficiently fine to grind for a pigment. The native sulphide is called cinnabar, and it is the ore from which the metal is obtained. Sulphide of mercury can also be obtained by double decomposition. If sulphuretted hydrogen gas be passed into a solution of nitrate or of chloride of mercury, a precipitate is thrown down which changes colour during precipitation: at one time it is whitish, it then becomes orange, and eventually black; the black precipitate, when washed and dried, becomes a black powder, having the same composition as that produced by rubbing mercury and sulphur together. It can be sublimed in the same way, and can be converted into the red form by friction. Any one desiring to perform this experiment can do so easily. The apparatus for generating hydrogen (Fig. 1) can be employed. Instead of putting zinc into the bottle (A), sulphide of iron, which can be bought for sixpence a pound, should be used, and dilute oil of vitriol should be poured in through the funnel (*a*); sulphuretted hydrogen will then be given off, and will soon be detected by its peculiar smell, which resembles that of rotten eggs; the gas will be conducted through the delivery pipe (c) to the end of which a piece of glass tube, about six or seven inches long, should be attached by means of a bit of india-rubber tube, and this should be inserted in a test tube containing a solution of chloride of mercury, commonly, by druggists, called corrosive sublimate; the solution should be handled with great care, as corrosive sublimate is, even in small quantities, a deadly poison. It is well to put the dilute oil of vitriol slowly into the bottle (A), as then the action will not be too rapid, and the changes of colour of the precipitate will be readily seen. The operation of subliming is not so easily performed by those who have not access to a regular laboratory, as it is almost necessary to heat the hard glass tube and its contents by the flame from a bellows blowpipe; if, however, such a source of heat is at command, all that is necessary is to procure a piece of hard glass tube seven or eight inches long, and three-quarters of an inch in diameter, and closed at one end; into this the black sulphide, *perfectly dry*, should be put to the depth of about one inch and then heated to a high temperature. The wet sulphide, made by the process just described, should be put on a filter paper placed in a glass funnel, and when the liquid has run through, it should be washed with distilled water, which should be three or four times poured into the funnel; it can then be dried; the best way to do this is to stop up the small end of the funnel with a piece of cork and place it in a beaker glass containing some water, and then by boiling the water its steam will

dry the contents of the funnel perfectly (Fig. 2). This is a very good way to dry all precipitates.

For some time vermilion was largely made in Holland; the process adopted was what we will call the dry method. Mercury and sulphur, about 170 lbs. of the former to 50 lbs. of the latter, were heated together, the sulphur melted, and the two were stirred gradually, the operation being performed in an iron pot. The temperature was not allowed to rise too high. The black mixture was, when completed, poured out and allowed to solidify on an iron plate; it was then broken in pieces, and kept in jars rather larger than a pint pot. The cylinders in which the vermilion was made were about four feet high; they were made of fine clay, and strengthened with iron bands on the outside. These cylinders, glazed inside and stopped at the bottom, were placed in a suitable furnace and heated; when red hot the black sulphide was thrown in, a jarful or two at a time, till a sufficient charge had been placed in the cylinder; the fire was kept up till the flames played over the top of the subliming pot or cylinder, and after a while the flames moderated, and when they played only a few inches above the thick smooth iron plate, with which the mouth of the cylinder was closed, the plate was removed and it was found to be covered on its lower surface with beautiful vermilion; that which had collected on the upper part of the inside of the cylinder was pushed down, and a fresh plate put on, on which more vermilion collected, and in this way the greater part of the black sulphide of mercury was converted into the red variety, or vermilion, which was subsequently ground in water. Other methods of making vermilion by the dry process have been adopted in different places, but they all proceed on the principles just described; it would be useless in an article like this to go into their special details. There are, doubtless, some trade secrets kept by different makers, but these do not concern us, the chemical action in all cases is the same, and these secrets can but refer to manipulative processes, which are, however, of great importance in the production of a *uniform* and beautiful tint.

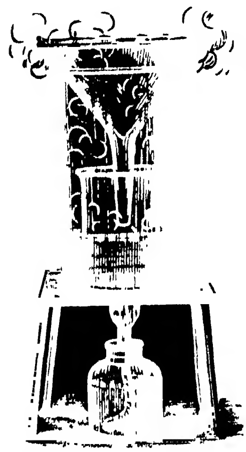


Fig. 2.—Showing the method of Drying Precipitates.

Vermilion can also be prepared by a wet process which is extremely interesting, and here it is quite possible for an amateur to experiment. If mercury and sulphur be rubbed together, as already described, a grey powder is formed; if this powder be placed in a Berlin dish with a solution of caustic potash (133 parts of potash to 150 parts of water by weight), and if it be kept at a temperature of 45° C. for a time, the colour of the sulphide will be changed gradually, and at last a very brilliant vermilion will be obtained. The temperature must never be allowed to rise above 50° C., for if it do so the tint will become brown. The author has often performed this experiment with success. The mixture must be stirred occasionally, and fresh water added from time to time, to take the place of that which has boiled away; the fresh water should be added warm.

Sulphide of mercury is insoluble in nitric acid—whether the black, formed by precipitation, or the red, made in any of the ways described—and this property enables us to detect some of the substances with which this pigment is often adulterated. When mercury is dear (as it was a few years ago, and large quantities of adulterated vermilion were brought into this country from abroad) the temptation to adulterate becomes very strong. The substances used for this purpose are generally red lead, red oxide of iron, and an organic matter called dragon's-blood, which gives a red colour. If a sample of vermilion, in powder, be treated in a test tube with nitric acid and boiled, if no change takes place the vermilion is free from iron or lead. If the nitric acid becomes yellow, iron has been dissolved in it, which may be proved by adding to the liquid, diluted with water, a few drops of a solution of ferrocyanide of potassium, which will immediately produce a deep blue colour. If the nitric acid be colourless, still it may contain lead in solution; to settle this point dilute some of it with distilled water, and add a few drops of iodide of potassium: if lead be present a bright yellow precipitate will be formed which will dissolve on boiling, and will be reprecipitated, on cooling, in brilliant yellow scales. If a portion of the sample be treated with alcohol, if dragon's-blood be present, a red solution will be produced. Pure vermilion, when heated on an iron pallet-knife, first turns black, and the sulphur burns off with a pale blue flame; after a time the mercury volatilises, and the whole disappears; if anything remains it is an adulteration. If iron be the adulterant, it will remain as red oxide; if lead, it will remain as yellow oxide, and will be fused or melted; and if dragon's-blood has been employed, it will give off a powerful odour.

There is considerable doubt as to what causes the different colours of the sulphide of mercury; the chemical composition of both the black and the red being the same. Exposure to a high temperature puts the black sulphide into such a condition that friction changes it to red; this seems to show that the colour depends upon what is called molecular arrangement. To explain fully what this means would take a long time, but in simple words it may be stated to be an arrangement of the minute particles of the *compound* which go to make up the mass, and as colour depends on the power which substances have of absorbing and reflecting certain rays of light, different arrangements of the particles of the same substance can be conceived to have a different action in these respects upon light. From the experiment last described, it will be seen that heat converts vermilion into the black sulphide. If vermilion, which is usually of a crimson tint, be ground very fine and washed continually, the tint will be changed to orange, and in this way orange vermilion is made. Vermilion, when pure, may be used with safety as a pigment, but when it is adulterated with lead pigments it turns brown, and even black, when acted upon by foul air, which contains sulphuretted hydrogen. In order to perform the tests to discover the purity of the paint, the vermilion should be rubbed up with water, put into a glass vessel, and be allowed to settle; the water should be poured off, and the process repeated till all the sugar and gum have been washed out. This method of getting rid of the gum, &c., may be adopted with all heavy colours.

"Light Red," "Indian Red," "Venetian Red."—The colouring matter in all these colours is the sesquioxide of iron, or ferric oxide. If some crystals of green vitriol, ferrous sulphate, be heated, the water of crystallisation will first be driven off, and then the mass will turn yellow, and a hydrated ferric oxide will be formed; if this be heated to a higher temperature it will turn red, as the water of hydration will be gradually driven off, and the tints assumed will vary as the expulsion of the water becomes more complete. This experiment is very easily performed on a piece of iron over a Bunsen burner, a spirit-lamp, or in a Berlin crucible; either should be held in crucible tongs, to prevent the fingers being burned. A Bunsen burner can be obtained for about eighteenpence at a chemical-apparatus-dealer's, and can be connected to a gas-burner by a piece of india-rubber tubing. If the red oxide so obtained be heated to a higher temperature, *i.e.*, to a white heat, its colour will change to a purplish-red—the tint observed in Indian red—a tint for the purity of which it is valued; this change in tint is owing to the formation of some of the black magnetic oxide of iron, for ferric oxide, at high temperatures, gives up some of its oxygen; and it will be remembered by those who have read the article on "Rust,"* that the composition of ferric oxide is twice fifty-six parts of iron to three times sixteen of oxygen, whereas the black oxide contains three times fifty-six parts of iron to four times sixteen of oxygen.

"Indian Red" is a natural product found in India. Its colouring matter is, as has been stated, red oxide of iron, but tempered with some black oxide, which gives it its peculiar purple tint; being an earth, it contains silica and alumina. The natural product is gritty, but it is very carefully washed; this washing is a very important operation in preparing all natural products for pigments. The earth is ground up with water, and the heavier particles are allowed to settle; the liquid is then poured into another vessel, and the finer particles subside first; the liquid above these is changed to another vessel, where the final subsidence of the remaining particles takes place. The colour is then ground very fine, dried, and mixed for use.

"Light Red" is made by calcining a very pure yellow ochre. The colouring matter of yellow ochre is the *hydrated* oxide of iron, so that when this is heated the water of hydration is driven off, and the anhydrous oxide of iron assumes its red colour. In making this pigment, great care is taken in the process of calcination, so as to secure the proper tint. Being an earth, it contains silica and alumina.

"Venetian Red" is an oxide of iron, more scarlet in its tint than the other reds, which owe their colour to the red oxide of iron. No doubt it was originally a natural product made from hæmatite, a mineral principally composed of the red oxide of iron; but now Venetian red is artificially prepared. Specimens of it which have been examined by the author have been found to contain sulphate of lime, and this leads him to suppose that in making it, a solution of sulphate of iron had been treated with lime so as to precipitate the oxide of iron, and this, with the sulphuric acid of the sulphate of iron, had formed sulphate of lime, a substance known as plaster of Paris. The precipitate thrown down in this manner is of a dirty-grey colour, but on being dried and heated to a red heat, it assumes a red colour. It is maintained by some writers that

* "Science for All," Vol. II., p. 241.

Venetian red is made by calcining sulphate of iron. This may be so in some cases, but sulphate of lime occurs in much of it that is prepared as a pigment. Nor is the presence of this substance in any way injurious to its properties as a paint; it is very stable, and may be used with safety in water-colour painting. As it contains sulphate of lime it cannot be used in what is known as silicious painting, because, with silicate of potash, sulphate of lime sets immediately, forming a hard compound which, after a time, disintegrates and breaks up. It was from its behaviour with silicate of potash that the author suspected that it contained plaster of Paris, and subsequent investigation proved that the suspicion was correct.

It is very easy to detect the presence of iron in a pigment after washing out the sugar and gummy matters, as described in the treatment of vermilion; if the solid matter which remains be dissolved in hydrochloric acid, and the liquid be filtered off from any insoluble matter, which will always be there in the form of silica in pigments which are prepared from natural earths; if it then be put into a test-tube and be boiled with a drop of nitric acid, to ensure the conversion of ferrous into ferric oxide —for in one pigment (terra vert) iron exists as ferrous oxide—it will then be in a condition for testing. The addition to this liquid of ferrocyanide of potassium will give a blue colour, and a precipitate on standing, if the quantity of iron present be small, but an abundant blue precipitates *at once* if it be present in large quantities. Sulphocyanide of potassium or ammonium will change the colour of the solution of the ferric salt to a rich crimson colour, more or less intense, according to the quantity of iron which it may contain. There are many other tests for iron, but these are sufficient to determine its presence with certainty.

"Pure Scarlet."—Some colour-boxes contain a cake of "pure scarlet." It is used in flower-painting. It is thought well to mention it here in order to warn persons against it, as being a compound easily decomposed, and therefore very fugitive in colour. When well prepared its tint is very beautiful, which makes one wish that it were more stable. If to a solution of corrosive sublimate, already mentioned as a deadly poison when treating of vermilion, a solution of iodide of potassium be added, a precipitate will be thrown down. If only a small quantity of the iodide be added at a time, directly the precipitate is formed it will be dissolved up again, showing that it is soluble in excess of the corrosive sublimate solution, but if more iodide be added the precipitate will remain. It is at first of a pale salmon colour, but on standing for a short time it becomes of a beautiful scarlet tint. It is soluble in excess of iodide of potassium, which may easily be proved by adding more of that substance to it. The precipitate is iodide of mercury (mercuric iodide). If a wash of it be put on paper and kept for some time, the red colour will diminish in brightness and the paper will be stained yellow. If the wet paint be rubbed with an iron palette-knife it will be decomposed at once, and the colour will change to a dirty grey; therefore no iron must be allowed to touch it, or, in fact, any other metal. If in painting it is allowable to use it at all, it should only be employed in what is called oil-painting, by itself, and mixed with a good, quick-drying, hard varnish; it should *never* be used in water-colour painting.

"Lakes" are prepared by the precipitation of the colouring material from certain solutions of organic colouring matters, animal and vegetable, by alumina or some other metallic oxide. Alumina has the property of uniting readily with colouring matter, and precipitating it in an insoluble form. It is on this account used as a mordant in dyeing—that is, as a substance to fix the colouring matter of the dye, so as to prevent its being washed out; to make it "fast," as it is termed. Lakes are made in various ways, and the brilliancy of their colour depends upon the great care taken in their manufacture, and on the accurate adjustment of the materials used, as well as on the temperatures employed in their precipitation and in the process of drying. If to a solution of cochineal a solution of alum (free from iron) be added, and both be warmed, after standing some time a precipitate will fall down, the alumina of the alum will carry down some of the colouring matter of the cochineal, and the result will be crimson lake. Other matters besides alumina will carry down the colouring matter; sometimes a tin salt is used, and then oxide of tin becomes the precipitant. Tin is said to improve the colour. I have been informed by some of the largest manufacturers of lakes in this country that they never use tin. Carmine is a lake, and is made by using a stronger solution of cochineal; it therefore contains more colouring matter. Carmine is sometimes prepared in the following way:—Freshly precipitated alumina is added to the solution of colouring matter, the mixture is warmed, and the precipitate allowed to settle; it is then filtered and dried. Lakes are also made from an infusion of Brazil-wood with alum,

but they are inferior in colour to those prepared with cochineal. The colour of cochineal carmine and lake is very fugitive; it is readily acted upon by light. If a piece of paper be covered with a wash of lake or carmine, and if half of it be exposed to sunlight, the other half being kept in the dark, that which has been exposed will gradually lose its colour, as may be seen by comparing it with the other half after the lapse of some time. The fugitive character of this paint is very unfortunate, as its colour is so very rich and beautiful. There are, however, lakes and carmines prepared from a different colouring matter which are very stable. Madder, which is obtained from the root of *Rubia tinctorum*, is used largely as a dye, and is also employed in the preparation of carmines and lakes. The root finely ground is soaked in water, and to the coloured solution, which has a beautiful pink tint, alum is added. The mixture is heated to the temperature of boiling water for four hours, it is then filtered, and carbonate of potash is added, which precipitates the alumina with the colouring matter of the madder. Madder carmine is made from a stronger solution of the madder root. Madder colours may be used with safety, as light has no action on them. Yellow lakes, which are very unstable, are prepared in a similar way from a decoction of Persian berries mixed with a solution of alum and precipitated by soda. Quercitron and arnatto are also used for making yellow lakes. It may be well to mention that, as madder is very expensive, colours made with it are sometimes imitated and adulterated. Many specimens from abroad have been proved to be so, cochineal and safflower being used for the purpose. In order to detect these frauds a solution of ammonia can be used, in which cochineal and safflower colours are soluble, whereas those obtained from madder are not. When a pure madder colour is treated with ammonia it remains unchanged, the liquid remaining colourless; whereas, in the case of the imitation, the ammonia becomes coloured.

"Yellow Ochre" is a natural earth, and is prepared by washing and grinding. Various tints of yellow ochre can be obtained, according to the qualities of the earths, which are found in different localities. Roman ochre, Oxford ochre, and many others, are named as pigments; the care taken in washing and preparing has a great deal to do with the beauty and tint of the paint. The ochres are all coloured with hydrated oxide of iron, and contain silica and alumina. They are very permanent; specimens of them are preserved which were used centuries ago. All ochres can, by calcination, be converted into reds; how this happens has been already explained.

"Gamboge" is a vegetable pigment, and is obtained from certain plants. Its principal source is a tree called *Garcinia Morella*, of the order Guttiferæ, which grows in Cambodia and Siam. The juice is obtained from the leaves and branches, which are first bruised. It is collected in suitable vessels, where it thickens. It is sent to market in various forms. Gamboge is a gum resin; in its natural state it does not dissolve in water, but when rubbed up with it forms a yellow emulsion. When a lump of it is broken it has a conchoidal fracture. It has powerful medicinal properties, acting as a purgative. It is soluble in alcohol, and from its solution can be precipitated in the state of a fine yellow powder, and in this form it is usually made into cakes for the colour-box. Gamboge has decidedly acid properties; it decomposes carbonate of potash or of soda, on boiling, and the salts formed are red, which can be precipitated, like soap, by common salt. Gamboge is a fairly permanent pigment. Ammoniacal vapours affect it and darken its tint; light has but little action upon it. To water-colour painters it is a very useful pigment, but it is rarely used in oil painting. Artificial gamboge is sometimes made from turmeric and other materials, but it is not good, and by no means as permanent as the true article.

"Cadmium Yellow" is made from sulphide of cadmium, and is not liable to be affected by foul air. When pure and well made, it is a very reliable pigment, but from the price of the metal cadmium being high there is great temptation to adulterate it with cheaper materials which do not injure the delicacy of its colour. There are several methods by which the sulphide of cadmium can be prepared. First, by passing sulphuretted hydrogen gas into a solution of a cadmium salt—the chloride or nitrate, which can be obtained of any chemist, will do; as the gas passes into the solution, a light yellow precipitate is thrown down; when all the cadmium is precipitated as sulphide, the contents of the test-tube, in which the operation is conducted, should be thrown on a filter paper in a funnel, and washed; the yellow precipitate can then be dried in the manner already described. A second method is to volatilise the metal cadmium with sulphur in a hard glass tube, out of contact with air—this condition is secured by having the tube closed at one end; here a darker and richer yellow is obtained, and tints approaching to orange-red can be procured. Considerable practice and experience

are required to produce certain results, but it is very easy to try the experiments, which will convince the operator of the general character of the compounds formed by the different methods described. Here the difference of tint in bodies which are of the same chemical composition is due to the different conditions of the minute particles which form them. The substances with which cadmium yellow may be adulterated are the chromes, which, being colours containing lead, are liable to suffer from the action of foul air; this adulteration is very easily detected by the colour darkening under the influence of sulphuretted hydrogen.

"Chrome Yellow."—There are several tints of chrome yellow, lemon and orange chromes being the chief; others, such as deep orange and red, are sometimes used. But we shall confine our attention to yellow and orange chrome. These colours are made from chromate of lead. If a solution of bichromate of potash be added to a solution of nitrate of lead, a yellow precipitate is obtained, much brighter in tint than cadmium yellow. If this be filtered, washed, and dried, chromate of lead fit for making a cake of colour will be obtained. Before drying, but after filtering and washing, take some of the moist chromate, put it into a test-tube with lime-water, and boil; its colour will change to orange, which will be deeper in tint the longer it is boiled, until the action is complete; this can be filtered, washed, and dried, and powdered orange chrome will be the result. The space allowed for this article will not admit of a full explanation of the interesting chemical changes which take place in these experiments; but a few words may be written which will give some idea of them. Nitrate of lead is a compound of nitric acid and lead oxide. Bichromate of potash, which gives a deep yellow solution, is a compound of chromic acid and potash, which is an oxide of potassium; when mixed in solution the acids change places, so that nitrate of lead becomes chromate of lead, and chromate of potash becomes nitrate of potash, or what is commonly called saltpetre. Then, when the yellow chromate of lead is boiled with lime-water, the lime takes away from it *some* of the chromic acid, so that after boiling long enough, chromate of lime is formed, some chromate of lead remaining chemically united with the oxide of lead, which has lost its acid to the lime; the chemical name for this body is basic chromate of lead. At the works of Messrs. Winsor and Newton, after the precipitates have been thoroughly washed, in the moist state they are put into absorbent moulds, and when the water has nearly left the colour, they are dried in storerooms heated to a tolerably high temperature by steam-pipes. All colours containing lead, in any of its combinations, are liable to turn brown and eventually black by foul air or sulphuretted hydrogen. In fact, so very marked and rapid is the action, that it is very easy to tell whether a pigment contains lead or not, by exposing it for a short time, in a moist state, to a current of sulphuretted hydrogen gas, or to the action of water in which this gas has been dissolved. From this tendency to change colour, pictures painted with lead colours should be so framed that air can have but moderate access to them. Water-colour paintings are, when framed, always glazed, and are not therefore so exposed as oil paintings; but then the oils and varnishes used in painting, if good, serve as a protection to the paints for some time; but water-colour pictures are not so protected, and therefore, when exposed to foul air, they change tint much more rapidly where lead colours have been used than oil paintings. There is no need to use lead colours at all, and artists who really care about the stability of their works should reject them. But many do not—a matter of no very serious moment to posterity in the case of very many modern English pictures, though picture-dealers may suffer by the deterioration in value of their property.

Most of the *greens* used in water-colour painting are unsatisfactory. Sap green is made from vegetable juices, and is very unstable. The berries of the buckthorn, the green leaves of the woad, and other vegetable substances are used in its preparation; these, when pressed, yield a liquid which is evaporated, and the residue is made into cakes.

"Emerald Green" is a compound containing arsenic and copper, and is therefore *very poisonous*. If arsenic—the common white arsenic of commerce—be mixed with acetate of copper in solution, a bright green precipitate will be formed; this, washed and dried, gives emerald green. It is an unpleasant pigment to work with; its tint is very violent; it is very poisonous, and not stable; with cadmium yellow it is decomposed at once, and turns brown. This would be an interesting experiment to try, as it would show readily how some colours act upon others when in contact, destroying each other's chemical composition and, therefore, colour. Rub a little emerald green on a white plate, also some cadmium yellow, and then mix them together with a palette-knife, and their colours will soon begin to go

"Prussian Blue" is prepared by mixing together solutions of ferrocyanide of potassium and ordinary sulphate of iron. As these experiments are easily performed, and are interesting, it would be well to try them. Dissolve some crystals of ferrocyanide of potassium, also called yellow prussiate of potash, also some sulphate of iron or green vitriol, in different test-tubes and in distilled water; then pour one into the other, and a dirty pale-blue precipitate will be the result. In another test-tube dissolve a *very small* quantity of bichromate of potash; to the blue precipitate add a few drops of oil of vitriol, and then pour into it the solution of bichromate of potash; instantly the blue precipitate will be made of an intensely dark-blue colour; when this precipitate has been filtered off from the liquid, washed, and dried, it will yield pure Prussian blue. The method here described is that by which this colour is commercially prepared. Another and more simple way of arriving at the same result is to add a solution of sesquichloride of iron to one of ferrocyanide of potassium. Prussian blue is a very beautiful colour, and of great use to the painter in water-colours. With gamboge and other colours it makes beautiful greens, and with white its gradations of tint are true blues. It is a good pigment, only being injured by some mixtures which cannot well occur if the pigments described in this paper only are used. The colour of Prussian blue is destroyed by alkalies, but restored by acids.

"Antwerp Blue" is of the same chemical composition as Prussian blue, with this exception, that it contains some alumina. The presence of the alumina seems to enliven its tint, though it somewhat interferes with the depth of its colour.

"Ultramarine" is of two kinds, natural and artificial. Natural ultramarine is prepared from a mineral called lapis lazuli: it is, in fact, the colouring matter of this substance, which is extracted from it by purely mechanical means. The stone is broken into lumps as large as nutmegs; it is then heated in a furnace to a moderate temperature, and then quenched in vinegar, which renders it friable, and also dissolves out carbonate of lime, which is always present in the ore; afterwards it is ground to a fine powder, which is levigated for a long time with a thin syrup of honey and dragon's-blood; it is then made into a paste with resinous matter, wax and linseed-oil; after some days the mass is treated with water, and the colouring matter is slowly washed out. The colouring matter yields different tints, and these are separated by suspension in water, the heavier particles subsiding first. Lapis lazuli is very costly, and the process of obtaining the ultramarine very tedious; therefore the paint is very expensive, being worth its weight in gold.

Artificial ultramarine is made by mixing freshly precipitated silica and alumina with soda lye till it is saturated; there must be no iron present; the proportions of silica and alumina must be as 31 to 36 of the dry materials; the dry residue is powdered, and mixed with flowers of sulphur in equal parts. These substances are carefully mixed and closely packed in a crucible, which should be full; the crucible is covered tightly, and then heated as quickly as possible to a red heat; if heated slowly, the sulphur would be vaporised before it had done its work. The crucible is kept at this temperature for two hours. It is allowed to cool slowly, the cover and luting being left on. When broken, its contents are of a green colour. The green ultramarine is put into a porous crucible and heated, when its tint changes to blue; it is then washed carefully and prepared for use.

Ultramarine resists the action of alkalies, but is at once destroyed by acids. If hydrochloric acid be poured upon it, sulphuretted hydrogen is evolved. It can be detected by its odour, and the blue colour is immediately destroyed. Nitric acid and sulphuric acid also decompose it. If blue ultramarine be heated in air it becomes green, but if sulphur be added to it before heating it retains its colour. Chlorine gas destroys its colour at once.

"Indigo" is a vegetable colour, and is obtained from several different kinds of plants, but principally from the various species of Indigofera. The *Isatis tinctoria*, or woad, also yields it in small quantities. The blue colouring matter of indigo does not dissolve in water or alkalies, but if some of its oxygen be taken away by what are called reducing agents it becomes white, and this can be dissolved in alkaline solutions, but not in water. If this solution in alkalies be exposed to air, the white indigo takes up oxygen and becomes blue, and this, not being soluble in alkalies, is precipitated. Indigo is prepared from the dried leaves of the plant. They are put into cold water for some hours. A kind of fermentation ensues. The fermentation must not be allowed to go too far, or the colouring matter will be destroyed. When the fermentation is completed the liquid is drawn off, and it is a yellowish-brown solution. This is agitated for some time with pieces of wood, to bring it in contact with the air, by which it is oxidised, and the blue indigo falls to the bottom,

forming a sediment, which is drained, dried, and packed for the market. Indigo is therefore manufactured abroad, and is sent ready for use to this country, where it is purified and prepared by the artist's colourman. Indigo is particularly useful to the water-colour painter, both for its tone of colour and for its stability when used carefully. It does not mix well with white-lead, but white-lead should never be used in water-colour painting.

"Cobalt Blue" is a very beautiful and enduring colour. It is made by precipitating a solution of a cobalt salt with alumina, then drying and heating the precipitate to a high temperature. Cobalt salts are pink in solution, and the precipitate of alumina and oxide of cobalt is of a pinkish-purple colour; but when it is heated it assumes a very beautiful permanent blue tint.

"Smalt" is also a compound containing cobalt, and deriving its colour from it. Smalt is really a cobalt glass; it is made chiefly in Germany. A very pure mixture of the substances which make glass is added to oxide of cobalt and fused in a crucible; a black glass is the result, which, when ground, yields a beautiful purple-blue tinted powder; if the powder be ground too fine, the colour is impoverished. It is difficult to lay on washes of smalt, and this is owing to the fact that the particles of the colour are hard and sharp, and must not be too fine. Other matters than true smalt are often sold for it; many smalts are adulterated with phosphate of cobalt.

"White-lead" is rarely used in water-colour painting; it should be discarded altogether. White-lead is in its chemical composition a carbonate of the oxide of lead, often containing oxide uncombined with carbonic acid. Space will not permit us to describe the manufacture of this substance, but it will be well to state how a person can easily tell whether he has white-lead or Chinese white. White-lead always effervesces when brought in contact with an acid. Put the specimen which it is desired to test into a test-tube, add water and a little nitric acid; if it is white-lead, it will effervesce like soda-water; then, when the effervescing has ceased, add water and pass in sulphuretted hydrogen gas, and the liquid will immediately throw down a black precipitate, which is sulphide of lead.

"Chinese White" is oxide of zinc. Oxide of zinc is best prepared for making pigments by burning zinc in a current of air. It can be made by precipitation, but precipitated oxide of zinc is not dense enough for the artist's purpose. Oxide of zinc is beautifully white, does not suffer from exposure to air, and can be used with pigments which white-lead injures. In water-colour painting there can be no objection to its use, but many will not use it in oil paintings from its not having as good a body as white-lead, and because it is somewhat more troublesome to work with. Oxide of zinc is not injured by sulphuretted hydrogen, because sulphide of zinc is white.

"Permanent White."—A cake of this pigment is sometimes put into the paint-box; it is, I believe, never made up as a moist colour, because too much saccharine matter and gum interfere with its body, and cause it to look grey when wet, although it goes quite white when dry; this change of tint on drying is an objectionable property. Permanent white, or, as it is sometimes called, *constant white*, is not affected by foul air, and does not interfere with other colours when mixed with them. It can be made by adding a solution of sulphate of soda to one of chloride or nitrate of baryta; when the two solutions come in contact, a dense white precipitate is thrown down; this should be washed and dried, and is then fit to use with a little gum-water. Sulphate of baryta—that is the chemical name of the paint—occurs native, it is called heavy spar; when native sulphate is used it should be ground fine and washed with acid, hydrochloric will do, in order to remove any iron with which it may be contaminated.

"Raw Sienna."—This pigment should be classed among yellows; but it is noticed here because it is closely allied to burnt sienna. Raw sienna is a natural pigment, its colouring matter is hydrated sesquioxide of iron; it contains silica and alumina in some quantity, more than the ochres contain, and therefore it yields a much more transparent pigment. It is a very useful colour to the artist, is perfectly trustworthy, and, when the pieces of earth from which the paint is prepared are carefully picked, gives a very beautiful though not pure yellow.

"Burnt Sienna" is prepared by calcining raw sienna; the hydrated oxide losing its water becomes the anhydrous sesquioxide of iron, and the process of calcination renders it more transparent than the natural earth. Like raw sienna, it is perfectly stable.

"Raw Umber" is a native earth; its colouring matter is an iron ore called *brown* hæmatite, which is a hydrated sesquioxide of iron, and manganese. These metallic oxides are mixed mechanically with clay, so that on analysis this earth is found to contain silica and alumina.

"Burnt Umber" is made from the same earth by

heating it to a high temperature, which changes the colour of the oxide of iron and causes it to assume a warmer and darker tint.

"Sepia" is an organic pigment, obtained from the contents of a sac connected with the secreting glands in the cuttle-fishes. This juice, which is of a very deep tint, is used—as our readers are doubtless aware—by the fish to secure its escape from the enemies who seek its destruction. A very small quantity of the liquid is able to colour a large quantity of water; one part is said to be able to render quite dark one thousand parts of water. When the juice is extracted from the sac it is very quickly evaporated and dried, otherwise it would putrefy and become useless. It does not really dissolve in water, but it can be suspended in it in a state of very fine division. When the sepia is dried it is heated with a little caustic alkali, which does not destroy its colour; it is rubbed up with it for some time, and then boiled in more alkali for about half an hour; it is then filtered, the alkali is neutralised with an acid, and a brown precipitate is thrown down, which is washed very clean, and is then made up in the usual way. This pigment is very stable, and of great use to the artist.

GETTING WARM.

By William Ackroyd, F.I.C., etc.

Any one passing not long ago along the main street of a busy town in the West Riding of Yorkshire might have observed a very curious fact—the lower halves of several large plate-glass windows were rent from side to side. A single glance was sufficient to show that the cracks were not produced by the stray missiles of certain street Arabs, for they had not that radiating or star-like arrangement which is generally seen in such cases, but, instead, consisted of one large rent proceeding from one side to the other, with one or two minor cracks branching therefrom (Fig. 1). To account for this curious and highly inconvenient phenomenon was a sore puzzle to many of the good folks about; some there were, however, more knowing than the rest, who arrived at a sensible and satisfactory explanation, thereby proving what is perhaps demonstrated every day, nay, every hour—that science is only, to use the words of Huxley, trained and organised common sense.

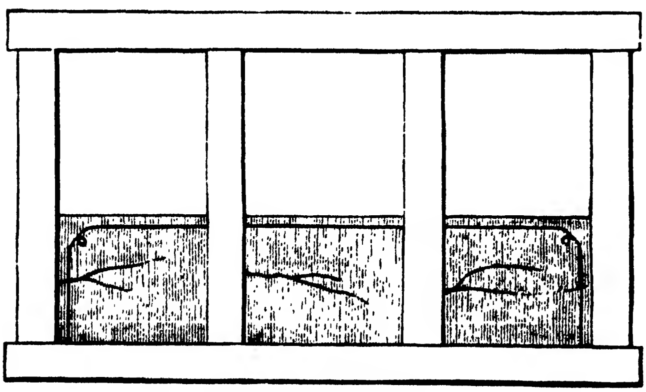


Fig. 1.—Cracked Windows.

It was midsummer. The windows of the shops where these cracks were to be seen faced the south, and were therefore exposed to the full glare of the sun's light and heat. The lower halves of the windows—*i.e.*, the cracked parts—were painted, on the inside, of a dun colour, and by two in the afternoon had become quite hot to the touch, whereas the upper and unpainted halves were only slightly warmed. Herein lay the secret.

When a substance is being warmed it expands, grows bigger in every direction, and the following simple experiment (Fig. 2) well illustrates the fact:—A rod of copper or brass, A, just fits lengthways between the ends of the metal gauge, B, and its diameter is such that one end of it fits tightly into the hole, C, when neither is the hotter—that is, when both gauge and rod are of the same temperature. If now the rod, A, be heated in a gas flame, it will be found that it can neither be thrust into the hole, C, nor adjusted lengthways in the gauge as before; for this heating has made it larger in every direction, so that it is too thick to fit into the round hole and too long to fit into the gauge. This fact, which is here so well shown, may be proved in many other ways equally simple. We may here give one, and then we shall show that the fact is usually recognised in the arts, and taken advantage of or allowed for as the case may

be. Let a flask, A (Fig. 3), be quite filled with water, and then fitted with a cork through which a glass tube has been previously passed. As the cork is being thrust tightly into the vessel the water will rise in the tube, say to *a*. Now place the flask in a basin of hot water. The first thing noticed is the fall of the liquid column to *b*. The process of warming the flask has made it expand, its capacity has been increased, and the water in the tube falls to take up the increased space. This does not last long, for soon the water within becomes warm, and now it expands likewise, and there is a race in expansion between the water and the flask, in which the latter has got the start. The water expands the faster of the two, however, so that soon the liquid column has reached *a* again, passed it, and arrived at *c*.

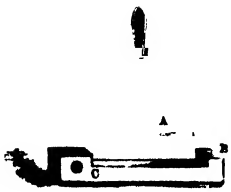


Fig. 2.—The Expansion of Metals.

And now for an example or two where the artisan makes use of, or an allowance for, this nearly universal law. The cartwright who wants to fit the iron rim tightly on to a cart-wheel takes that rim and heats it in the fire until it is red hot, thus making the rim much larger than it would be in a cold state. The rim is now pressed on to the wheel, cold water is poured on to it, and in regaining its usual size in getting cold it clasps the woodwork in a vice there is no escaping from. Again, the reader may have noticed that in a tramway the ends of the iron rails are not in contact; there is a small space between each to allow the metals to expand on hot days. If this allowance were not made—if the metals were in contact end to end on a cold day—then, when it became warmer, Nature, relentless, and as if in scorn at man's work, would tear up those rails, sleepers would be riven up, and bolts bent as if in play. What we have imagined in this last instance is the nearest approach to what took place when the plate-glass windows were broken. The glazier fixed the windows as if they had been small panes, where the amount of expansion is very minute indeed, and they were fixed in a rigid framework that would not give way. The painter, on his part, in his ignorance of certain principles we shall presently explain, put on a colour which led to the glass being strongly heated in the sun's rays. This followed: the plate-glass was heated, and it expanded; the frame of the window tried to restrict that expansion, and in the struggle the weaker had to give way, not doing so, however, until it was irremediably injured. The condition of the window-panes was not unlike that which Dr. F. Guthrie imposed upon specimens of glass of various shapes in a research on the fracture of such objects.* The accompanying six illustrations (Fig. 4) exhibit some of his results. The first, *a*, shows that

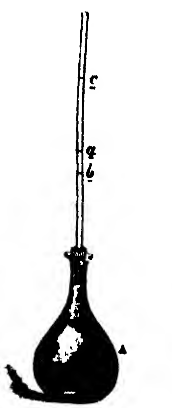


Fig. 3.—The Expansion of Water.

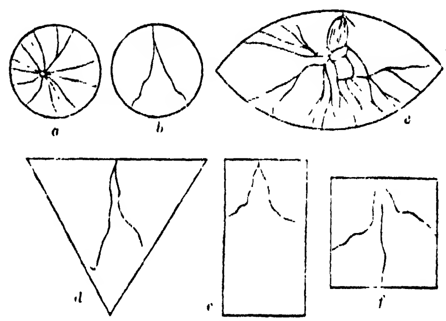


Fig. 4.—Guthrie's Experiments on the Fracture of Colloids.

when a round plate of glass is placed on a thick soft cloth, and is pressed in the centre by a round cork, it cracks radially—that is, the lines of fracture spread outwards from the centre. The remaining figures, *b*, *c*, *d*, *e*, and *f*, show what takes place when plates of glass of peculiar shape are heated in the centre with an air-gas burner. We have here a difference of temperature between the borders and central areas, which produces an internal strain that relieves itself by fracture. Of this series of breakages, *e* and *f* nearest approach the conditions met with in the window-panes. The rigid frame in the one case corresponds to the cold and comparatively non-expanding rim in the other; and there being a similarity in the conditions to which the glass in the two cases is exposed—viz., an expansion of a central area restricted by the comparatively non-expanding framework—there is a likeness in the cracks produced.

What was a mystery, then, is now a mystery

* "On the Fracture of Colloids." Proceedings of the Physical Society of London, Vol. III., pp. 76-81.

no longer, for it will be clear to the reader that the agent at work was the sun; and two other facts, from their boldness and prominence, equally command our attention: first, that the sun's heat passed quite through the bare glass; and second, that the sun's heat did not pass through the painted glass, the dun paint here evidently acting as an obstructionist. While we are, therefore, getting some idea as to the nature of heat, learning what is going on when a substance is being warmed, we shall do well to look for and inquire into the use of two classes of bodies—one class the members of which, like the glass, apparently allow heat to pass through them without stopping much, and the other which stop so much that they soon become sensibly hot, or at least permit only a small quantity to get through. In this search we shall be materially aided by considering the similarity, and in some cases the identity, of light and heat. They both come together from the sun, and we shall see that they behave alike when we submit them to certain tests.

Light is bent in passing from one medium to another; so is heat. The simplest proof of this is the action of a burning lens, which, when held in the sun's light, bends the heat-rays, just as it bends the light-rays, to a focus where objects may be burnt. It may be shown with one of the glasses of a pair of spectacles adapted for long sight, for if such a convex glass be held some inches from the back of the hand, so that the image of the sun is projected on to it, the heat will be very sensibly felt. Larger lenses are of course more powerful for this purpose, and we have seen that in times past effective scientific work has been accomplished in this way, as when Priestley discovered oxygen.* In the polar regions Dr. Scoresby has often lit fires and done other wonderful things with a lens made of ice. These facts, then, plainly show us that heat radiating from the sun is bent like light when passing through suitably-shaped media. The question now arises, To what extent is it bent?

In working out this problem many interesting facts have been discovered. When a solar beam is passed through a prism it is evident that a sorting of the different kinds of light is effected, each ray being gathered unto its kind—red to red, blue to blue, &c. Class distinctions here reign supreme, and it is found that *dark heat-rays* have precedence of the red light-rays, just as red light comes before the orange, and the orange before the yellow, in the solar spectrum. In the effort to get through the prism the dark heat-rays have the least trouble and the violet rays have the most. It will be seen, then, that the heat-rays are less bent than the light-rays, save where, as we shall presently try to show, light and heat are identical.

Fig. 5.—Position of Dark Heat-rays in the Spectrum.

Suppose now we were to employ a prism of rock salt (P, Fig. 5) in producing a solar spectrum, and were then to place a delicate thermometer in different parts of the spectrum, we should find that the highest temperature is registered a little beyond the red light, and that we should get lower and lower degrees upon testing each part of the spectrum on the way to violet. It would seem, then, that the ultra-red part of the spectrum is the most favourable for getting warm in, and that there is less and less warming power as we proceed towards the violet end. Let us regard these constituents of the solar beam now as they affect our organs of sense. The ultra-red rays have no effect on the retina; they are invisible—hence the phrase we have employed to designate them, *dark heat-rays*. When we come, however, to the red, if we were to concentrate this part of the spectrum on to the skin we should feel the sensation of warmth still, and the same rays passed into the

* "Science for All," Vol. II., p. 252.

eye would give one the sensation of light. Here, then, heat and light are identical, and we employ either one or the other term according to the nature of the physiological effect. The physical basis of the dark heat-rays and of the more easily bent light-rays is the same—viz., a wave motion of that all-pervading medium, ether, which connects atom to atom and star to star.

We have had occasion to speak before of the length of these ether-waves,* and we gave them then in fractions of an inch. Since, however, it is the prevailing custom, both in this country and abroad, to employ another measure, a word or two on the subject will not be out of place. The French millimetre is about the twenty-fifth part of an English inch, and in speaking of the lengths of these ether-waves, the unit employed, technically termed a *tenth-metre*, is the ten-millionth part of a millimetre. When one, therefore, says that a certain ray has a wave-length of 7,604 tenth-metres, it is meant that the wave is $\frac{7604}{10000000}$ of a millimetre long. The following are the wave-lengths of the more important lines in the solar spectrum,† according to Angström :—

Solar lines.	Wave-lengths in tenth-metres.
A	7,612
B	6,875
C	6,568
D_1	5,900
D_2	5,894
E	5,274
b	5,177
F	4,865
G	4,310
H_1	3,972
H_2	3,936

To return to our consideration of the warming power of different parts of the solar spectrum. It will have been noticed that the heat-rays are crowded together, as it were, at one end of the spectrum and gradually spread out at the other. In thinking over this matter, it appeared probable to the well-known American investigator, Dr. J. W. Draper, that if a given series of red rays were collected, and their warming power tested, it would be equal to that of an equivalent series of violet rays. He accordingly tried the following experiment. In a visible spectrum, he collected all the light of wave-lengths between 7,604 and 5,768 together, and also all that of wave-lengths between 5,768 and 3,933, the former belonging, of course, to the red half of the spectrum, and the latter to the half ending in the violet; and he found their warming power to be equal, as determined by the thermopile, an instrument we have already explained.‡ This result one might thus express :—Any series of ether-waves in the solar spectrum, the difference in length of whose extremes is a certain number of tenth-metres, has the same warming power as any other series of ether-waves with the same difference of extreme wave-lengths. In the case of Draper's experiment, it is seen at a glance that the differences of wave-lengths in the two series employed are approximately equal :—

7,604	5,768
5,768	3,933
1,836 tenth-metres.	1,835 tenth-metres.

We may now profitably resume our comparison of light and heat. *Light is reflected from a polished surface*§; *so is heat.* In the case of light, myriads of proofs constantly present themselves, because of the sensitiveness of the eye to light, and many simple proofs of the reflection of heat might be devised based on the sensitiveness of the skin. Get the tinker to beat out a small sheet of "tin" into the shape of a can-bottom, say a foot in diameter. A polished concave reflector will be thus obtained for a few pence, and with a couple of such reflectors the experiments on sound described on p. 129, Vol. I., may readily be repeated. Let there be a good fire in the grate, and take up a position at one end of the room where the heat rays are not felt, although their path is not obstructed. Now turn the concave side of such a reflector towards the fire, but bent sufficiently on one side to allow any rays that may fall on it from the fire to be converged on to the face. When this is done a feeling of warmth is experienced, showing clearly that the heat of the fire has been brought to a focus *by reflection*, just as light and sound would be under similar circumstances.

We might also show that the heat coming from the sun or the house-fire may be polarised like light,‖ and is subject to the same laws of interference;¶ but we shall content ourselves here with showing that *just as light may be absorbed so may heat.* In every coloured body, more or less of the light falling on it is absorbed, and the remainder, which produces the sensation of colour, is reflected; and it is plain that if the light absorbed is that which will produce the sensation of warmth when

* Vol. I., p. 362. † Vol. II., p. 126.

‡ Vol. III., p. 59. § Vol. I., p. 191.
‖ Vol. I., p. 197. ¶ Vol. I., p. 363.

directed on to the skin, then we have here likewise an absorption or drinking-in of heat. The heat-rays of a sunbeam are also absorbed by many substances that are transparent, and ice is one of these; for although we have seen that if a lens be made of ice, sufficient heat is passed through and converged to a focus to set many things on fire when the lens is held in the sun's rays, we likewise know that a few heat-rays are stopped by the ice, and therein melt it in the most beautiful and systematic manner. Tyndall has shown that when a bundle

Fig. 6.—Liquid Flowers in Ice.

of rays are passed through a slab of ice, beautiful six-petalled flowers are revealed, each with a bright spot of empty space in its centre, and they are liquid flowers formed in the melting of the ice (Fig. 6). In this manner, no doubt, glaciers, bergs, and other accumulations of ice are melted. They may, however, be melted in a much more expeditious manner by a process precisely similar to that by which the window-panes we have spoken of were over-heated. There the dun paint captured a large amount of the sun's heat-rays by absorption, became hot, and imparted a great part of its heat to the glass it was in contact with. So, in like manner, if the ice were covered with a coloured substance greedily absorbing heat, and sufficiently thin for the heat to pass through it, the underlying ice would soon disappear. The skater may frequently have noticed twigs, brown leaves, and straw sunk many inches in the ice. Being ready absorbents of heat, these fragments of vegetation have soon become warm in the sun's rays, have slowly sunk into little icy graves of their own making, and probably at the very next frost the water lying over them has been frozen. We have then seen a leaf or a twig in the middle of a solid block of ice, and have probably been as much puzzled to account for its presence there as the ancient geologists were bothered about insects embedded in amber. This melting of ice by means of coloured vegetables lying on them may have performed a most important part in the history of the world. In 1870 the Arctic explorer Nordenskjöld paid a visit to Greenland for the purpose of seeing which were the more suitable in the Arctic regions for sledging purposes, reindeer or Eskimo dogs. He and a companion had one long excursion out on the "inland ice,"* and everywhere they noticed vertical cylindrical holes a foot or two deep and from a couple of lines to a foot or two in width. In some cases the holes were so near each other that it was impossible to find room between them for the foot. Nordenskjöld invariably found at the bottom of them a grey powder, which had evidently been the means of stopping the sun's heat in the first instance, and afterwards of melting the ice. He remarks:—"When I persuaded our botanist, Dr. Berggren, to accompany me in the journey over the ice, I joked with him on the singularity of a botanist making an excursion into a tract perhaps the only one in the world that was a perfect desert as regards botany. This expectation was, however, not confirmed. Dr. Berggren's keen eye soon discovered, partly on the surface of the ice, partly in the above-mentioned powder, a brown, poly-cellular alga, which, small as it is, together with the powder and certain other microscopic organisms by which it is accompanied, is the most dangerous enemy to the mass of ice so many thousand feet in height and hundreds of miles in extent. This plant has, no doubt, played the same part in our country; and we have it to thank, perhaps, that the deserts of ice which formerly covered the whole of Northern Europe and America have now given place to shady woods and undulating corn-fields." But nine years before Berggren's observations, Dr. Robert Brown, during his researches in the same desolate region, had shown that Arctic ice was often coloured brown by the presence of Diatomaceæ, and was often seen to be honeycombed, having at the base of the cavities accumulations of these coloured microscopic objects.†

It is plain that in the brown alga, yellow straw, black twigs, and dark bodies generally, we have substances, like the dun paint, which readily absorb the heat coming from the sun or any other fierce heat-source, and lead to the melting of ice, on which they may rest at a much faster rate that when it is bare. It will be apparent, therefore, on this

* Brown, "The Pl
Papers of the Royal
"Science for All," Vol. I., p. 88.

† "Science for All," Vol. III., p. 22; "Arctic Manual," p. 311.

account, that a kettle coated with soot will sooner heat the water within it than another kettle that has been highly polished on its exterior. And now we may point out that these highly absorbing substances are exceedingly useful; for when they have received heat they give some of it out again, and thus warm the substances around them which cannot themselves absorb the sun's rays so readily. Nature's great rule of reciprocity is here strikingly illustrated: a good receiver of heat is a good giver, and gives lavishly of its abundance to the bodies which are around it; and, on the other hand, a bad receiver of heat parts but tardily with what it has absorbed. A glass flask containing hot water is longer in growing cool than it is when its surface has been lamp-blacked, because the lamp-blacked surface radiates heat better than the surface of bare glass; and the same flask filled with cold water would be longer in growing warm if put in the sunshine than it would be if its surface were lamp-blacked, because the lamp-blacked surface is a better absorber of heat than that of the bare glass. Hence, to keep the heat for a length of time within the flask, the worst thing we could do would be to cover its surface with a deposit of lamp-black or soot, and the best we could do would be to surround it with a worse absorber and radiator than the glass itself. For the latter purpose we should probably find the hairy coverings of animals very effectual, and probably better still those patent coverings for boilers, cylinders, &c., which inventors, taking a hint from Nature, have devised to economise the fuel employed by the manufacturer.

Another most important element we have now to take into consideration is distance, it being a matter of every-day experience that a substance may be warmed much sooner near the fire than a long way off it. There is a precise law which tells us the exact proportions of heat which two like surfaces in every respect receive at various distances; and in accordance with this law, if one of them, say A, be one yard off, and another, B, nine yards away, we know that B would receive only $\frac{1}{81}$ part of the heat received by A. The importance of our properly understanding this law is very great, because of its wide applicability. By means of it we can easily calculate the comparative amounts of heat falling on two surfaces at different distances from the house-fire, and in precisely the same manner we can ascertain the comparative amounts of heat that each wandering planet receives from the great central focus or fire, the sun. This law is known as the law of inverse squares. It will be readily understood from the following elementary considerations; and as it applies to light as well as heat, we may as well investigate the matter with regard to light. From the candle *c* (Fig. 7) light emanates in every direction and in straight lines. Suppose, then, we place a screen, *s*, a square yard in area, just one yard away from it, there will be behind it a pyramid of shadow. Now suppose this pyramid of shadow to be cut across at two yards and three yards from the candle, and screens *s′* and *s″* placed there just to fill up the section; the area of *s′* will be four square yards, and of *s″* nine square yards. Upon removing the screen *s*, it is evident that the light which fell upon it will be spread out to cover *s′*, which is four times its area; consequently, the light falling on a part of *s′* equal in area to *s* has only one-fourth the illuminating power of that which falls on *s*. Suppose now that the screen *s′* is removed, the light which at first fell on *s* will fall on *s″*, nine times its area, and being spread over nine times the surface, any square piece of it equal in area to *s* will receive but one-ninth the light which *s* receives. We thus see that three surfaces of equal area placed at distances—

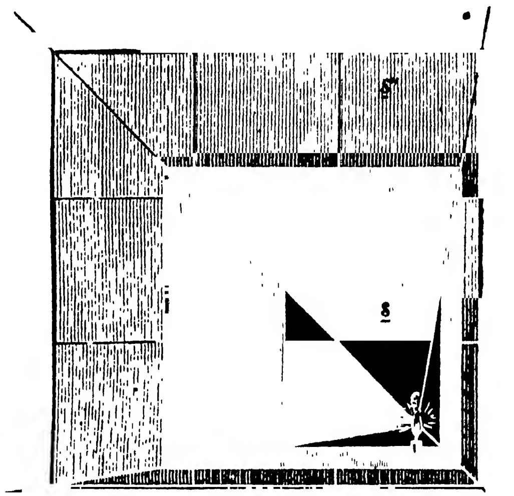


Fig. 7.—Illustrating the Law of Inverse Squares.

1, 2, and 3

from the candle receive amounts of light which may be expressed in figures, as:—

1, 1-4th, and 1-9th,

respectively. And as with light, so with heat; for it can be experimentally proved that the dark heat emanating from such a candle, and falling on screens of equal area in the positions *s*, *s′*, and *s″*,

are warmed to an extent which is expressed by the figures 1, 1-4th, and 1-9th. Taking the warming power of the rays falling on the first screen as 1, then the warming power of the rays falling on an equal area at double the distance is 1-4th, and at treble the distance 1-9th, or the warming power varies inversely as the square of the distance from the heat-source. Thus it is that the astronomer knows the warming power of the sun's rays when they reach each of the planets, and is able to furnish us with the following results, from which the reader will see that a square of planetary surface, say a mile in area, receives nearly seven times more heat on Mercury, and a thousandth less on Neptune, than it receives on the Earth:—

Planet	Warming power of Sun's rays.
Mercury	6·674
Venus	1·911
Earth	1·000
Mars	·431
Jupiter	·036
Saturn	·011
Uranus	·003
Neptune	·001

For getting warm, then, under the most favourable conditions there must be close proximity to the heat-giving or radiating body, and the recipient must have a very good heat-absorbing surface. If the giver and receiver of heat be in absolute contact, then the colder substance may get warm by *conduction*, even although it be an indifferent absorber. A poker is sometimes left in the fire, and the end in contact with the red-hot cinders soon becomes red-hot too. The heat at the red end flows towards the colder parts of the bar of iron, so that it would be dangerous to seize it some distance from the red-hot part. The process by which the heat has passed from the hotter to colder parts of the bar is termed *conduction*, and this quality of conductivity is possessed in very various degrees by different substances, so that we have good, bad, and indifferent conductors of heat, just as we have absorbers of every kind. There is a number of simple devices for showing this difference of conductivity; the following is one of them:—A metallic trough has a number of holes made along one side. These are closed by corks through which are passed rods of various substances—as copper, iron, wood, and glass. If now each of these rods be dipped in melted wax or tallow, they become coated with a thin film of that substance, which solidifies as soon as they are withdrawn. Let the rods now be placed in the apparatus shown in Fig. 8, with their unsmeared ends reaching into the vessel, and next fill the box with boiling water. The extent to which the heat is conducted along the different rods is roughly seen by observing the distances to which the wax or tallow is melted along them. In this way we should soon find out that the metals are the best conductors of heat. More refined experiments would teach us other facts respecting conductivity, as that the metals themselves vary in the degree of facility with which heat is permitted to flow along them, silver being the best and bismuth about the worst of metallic conductors; as that heat flows much more easily through certain substances in some directions than in others; and that there is a close analogy between heat conductivity and electric conductivity, the best conductors of heat being the best conductors of electricity.

Fig. 8.—Illustrating the Conduction of Heat.

When a pound of water at 30° C. is mixed with a pound of water at 50° C., the resulting mixture has a temperature which is the mean of the two—viz., $\frac{30+50}{2}$, *i.e.*, 40° C. This we should quite expect, for two separate pounds of water are two portions of matter alike in chemical composition and physical properties, and will therefore when mixed attain to a common temperature by a transfer of heat, which leaves one of the pounds debtor to exactly the same extent as the other is creditor in their mutual heat account. If, however, one of these pounds of matter had been different from the other in chemical composition and physical qualities, then, upon mixing them, we should have a very different state of affairs. Suppose now we take a pound of quicksilver and mix it with a pound of warmer or colder water, the temperature of the resulting mixture is not the mean, but one much nearer the original temperature of the water than of the quicksilver. Suppose the pound of quicksilver has a temperature of 40° C., and the pound of water one of 100° C., after well mixing, the mixture registers 98° C. In gaining this common temperature the water has lost only 2°, and the quicksilver has gained 58°, whence it is very plainly evident that unlike substances take different amounts of heat to warm them to the same extent. In the problem of getting warm it is, therefore, a point of some importance to take into consideration the kind of matter that has to be

warmed. Let us now turn to the figures for a few moments more. The 58° the quicksilver has gained are equivalent to the 2° the water has lost; whence it follows that a change of 29° in the quicksilver would be equivalent to a change of 1° in the water, and from which it is further clear that if we wanted to raise the pound of quicksilver only one degree we should require only $\frac{1}{29}$th the amount of heat which would be wanted to produce the same change of temperature in a pound of water. The quantities 1 and $\frac{1}{29}$ therefore show us the comparative amounts of heat required to produce a change of temperature of 1° C. in water and quicksilver respectively, and they are called *specific heats.* In the same way we might ascertain the specific heats of the other metals, taking that of water as the unit.

From all we have said it will be apparent that this operation of getting warm is a most important one from a philosophical standpoint, seeing that we have to take into account so many of the qualities of the body receiving that mysterious something, heat. Let us now inquire what this heat is. During the last century it was thought that when anything was being warmed an invisible substance, which philosophers were never able to weigh, was being made to enter it. They called this hypothetical body *caloric*, and they were firmly persuaded that when caloric was made to leave, say, a stone, the stone became cold, while, if the caloric was made to enter the stone and store itself amongst its ultimate parts, then the stone became hot. In process of time, however, some facts were discovered which this hypothesis of caloric thoroughly failed to explain. If there existed such a substance as caloric, then, like all other matter, it would be impossible to entirely destroy it or produce it from nothing. Heat, however, was plainly produced when a smith, to show his strength and dexterity, would take a piece of metal and beat it with a cold hammer on a cold anvil until it was too hot to touch. Where had the heat come from? The question became more startling still, when Count Rumford found that in boring brass cannon, the heat developed by the friction, even when the shavings of metal cut out by the borer weighed only a few ounces, was sufficient to make two and a-half gallons of water boil. The quantitative results in these experiments showed that the amount of heat produced is proportional to the work spent. And conversely in the experiments of Hirn, it was shown that when heat is made to do work in a steam-engine, part of the heat disappears, and the portion apparently destroyed is proportional to the work done by the engine. From these facts it follows that heat is not a substance, but a something very nearly related to the swinging motion of the hammer, the rotating motion of the borer, and the up-and-down rotating and revolving motions of a steam-engine; it is, in short, a motion of the molecules of a body exceedingly rapid and exceedingly minute. When, therefore, the bearing which supports a rotating shaft becomes very hot for want of oiling, we figure to ourselves a transmutation of this visible motion of rotation into an invisible molecular motion which we term heat. In making a substance warm, then, by whatever means we choose, we are agitating its molecules more and more, and we may carry this on until the molecules vibrate so quickly that they affect the ether which surrounds them, and so send off a continuous series of ether-waves, which, rushing against the skin, may give us the sensation of heat, or, coming against the retina, the sensation of light. If the motion of the ether particles be taken up by some substance other than these organic membranes, we have an absorption of heat similar to that we saw in the case of the dun paint. The dun paint may, again, communicate its molecular motion to any substance like the glass that it may be in contact with. Thus it appears the various facts concerning heat may readily be explained by this theory, for it is a structure of sufficient capacity to hold all the new facts which are being constantly ascertained. But while the scientific antiquary well sees that the mechanical theory of heat is more commodious than the ancient one of caloric, he is strongly impressed with the fact that its builders have largely availed themselves of the material presented to their hands by the demolition of the old caloric theory; he recognises the old stones of fact, although in many instances they have been redressed; and the main difference between past and present century work he traces to the more powerful and precise instruments, mental and material, which are now being employed by the scientific craftsmen in rearing and perfecting their theory.

HOW WE CLASSIFY LIVING BEINGS.

By Andrew Wilson, Ph.D., F.R.S.E., etc.

THE common meaning of the word "classification" is generally understood to be "arrangement" of one kind or another; and although such meaning is correct enough in its way, it is, at the same time, too general to be of utility in the exact paths and defined ways of scientific existence. To classify any series of objects is indeed to "arrange" them, but in the arrangements of science, *method* and *order* are circumstances which above all else have to be considered. Hence we must seek a more exact idea of the word "classification," before we can profitably venture to discuss, even popularly and cursorily, the question "How do we classify animals and plants?" Firstly, then, we may begin by saying that classification may best be defined as the process of bringing together things which are like, and of separating things which are unlike. The former process, indeed, includes the latter. When we arrange together the similar objects, we tacitly separate out the dissimilar ones. Any system of classification, worth speaking of as such, is thus really a work of placing together the like and eliminating the unlike. Grasping this idea, we shall find it to explain for us a vast deal, which might otherwise puzzle and confuse us in the study of natural history arrangements. But it may be likewise profitable to ask at the commencement of our studies, "Why do we classify things?" or, "What advantage do we gain from arranging animals and plants?" If we have seen the principle which guides us in the "how" of classifications, let us try to discover that which regulates the "why" of this important matter. In so doing, we may likewise gain an idea of the use and purport of the present paper. When we arrange together any set of similar objects, we thereby declare, as a matter of course, that there exists between the things in question some bond or degree of relationship. We tacitly express relationship by classifying things; so that a good and true arrangement is really, in its way, a guide to the nature of things. Moreover, there is another advantage gained by classifying any series of objects—namely, that the common characters in which they agree are the more readily appreciated by, and fixed upon, the mind that studies them. It becomes an easy matter to study objects such as animals and plants, when we find ready to hand a good classification of them. The characters and likenesses, as well as the differences between the various forms we study, are grouped together in a good arrangement, and the recognition of the main features of the objects is thus rendered a comparatively easy matter.

It may be said that any system of classifying anything must belong to one or other of two kinds of arrangement. Our classification must be either *artificial* on the one hand, or *natural* on the other; and as we are given in the great majority of cases to prefer what is "natural" to that which is "artificial," it may readily enough be supposed that the former classification possesses marked advantages over the latter. To render clear the difference between artificial and natural arrangements is by no means difficult. Let us select two instances of attempts at arrangement—one the case of the librarian, the other that of the naturalist. A heap of books is spread on the floor of a room, and a classification of them is required. A child with sufficiently marked ideas of size, colour, or style of binding, might arrange the books tastefully enough for us, by attending to one of these particulars. He would, in other words, place books of the same size, colour, or binding together. But of what utility would such a classification be to the person who, wishing to consult the library, was at the same time unacquainted with the books contained therein? Next the volume, say of zoology, he might wish to consult, there might be placed a volume of poems, and on the other side of the desired book he might find a treatise on architecture. There would be likeness, indeed, between the volumes so arranged, but it would be a similarity only in outward appearance after all; and the arrangement would be utterly useless for all practical purposes.

If such a result would be attained by a classification of books conducted on an artificial system, we see no less plainly that a similar arrangement of the animal or plant would fail in affording a true and adequate conception of the objects classified. Take, for example, the common arrangement of whales with fishes, by way of illustrating an artificial arrangement of the animal world. The whale is undoubtedly extremely fish-like in all its relations, as viewed from the popular standpoint. It possesses a fish-like body, it in-

habits the sea, and it lives a completely aquatic existence. Hence, to say that a whale is a fish, appears at first sight an eminently safe and justifiable assertion. Notwithstanding the likeness existing between these animals, however, there may be found ample reason for their complete separation in some very simple and common facts of natural history. For instance, the whale breathes by lungs, like ourselves, and, as every one knows, has to ascend periodically to the surface of the water, to inhale air from the atmosphere. The fish, on the contrary, breathes by gills; and in virtue of the possession of these organs is enabled to remain permanently in the water, and to extract from it the oxygen necessary for the aëration of its blood. The body-covering of the whale consists typically of hairs, although in the matter of such furnishing the whales, as a rule, are more or less deficient. The fish is, on the other hand, covered with scales; and whilst the whale is a warm-blooded animal, the fish is cold-blooded—that is, the temperature of its body is very little raised above that of the medium in which it lives.

The whale possesses a four-chambered heart and a perfect double circulation. The heart, as in ourselves, not merely sends blood to the lungs to be purified, but likewise distributes the pure blood throughout the body. In the fish, the arrangements for the blood-circulation are formed on a much more simple type. The heart in the fish is two-chambered to begin with; and its duties consist solely in sending the impure blood to the gills for purification; the heart in this case having nothing to do, in a direct manner at least, with the distribution of pure blood throughout the animal's body. Then lastly, and to avoid entering into the technical anatomy and physiology of whales and fishes, we may add, as an important point of distinction between the two groups, that the young of the whales are born alive and nourished by means of milk (Fig. 1); whilst the young of the fishes are hatched from eggs, and are developed, as a rule, independently of parental care and attention.

Fig. 1.—Hump Back Whale Suckling her Young.

We thus discover that the differences between whales and fishes are practically of immense extent. The fish we find to be a much lower animal

than the whale. Beyond the fact, indeed, that both are "Vertebrates," or "back-boned" animals, and that they therefore agree in the broad and general plan on which their bodies are constructed, there is little resemblance between them. The separation of the one from the other is, therefore, a matter of easy justification; and the arrangement together of whales and fishes is thus condemned by a simple appeal to elementary facts of the structure and function of these animals.

An example from the plant-world of a similar likeness, which on closer examination is proved to be thoroughly unreal in its nature, is presented in the case of the Euphorbias, of Africa and elsewhere, and the Cactuses, which are typically American in their distribution. To an inexperienced observer, certain kinds of the former plants so accurately reproduce the features of the cactuses, that they might be mistaken for plants of the latter kind. But botanically—that is, in their true nature, structure, function, and distribution—they are separated by differences which are of paramount importance in the eyes of the scientific student. Thus things are truly not what they seem in many cases of presumed likeness in the animal and plant world; and we may now proceed to inquire into the characteristics which make the "natural" classification the only true and exact means of setting forth the relationships of living beings.

Returning, for a moment, to our comparison of the library and its arrangement, let us suppose that an intelligent librarian sets himself the task of accurately classifying its included volumes. The external appearances of the books—their size, binding, and colour—would form points of no importance whatever in the estimation of the librarian. His aim is to place together those volumes which are really alike—which agree in their subject-matter, and even in special features of that matter. Thus a volume of Wordsworth's poems would not merely be placed amongst the volumes of poetry, but would, in a perfect system of library classification, be classified in a special section of the poetical department, and along with those volumes written, it might be, in similar style, or at the same period of literary development. Wordsworth's place on the library shelves would thus most appropriately be found beside Shelley, Southey, and Coleridge. Such an arrangement would be a thoroughly "natural" system of classifying the library; and would be paralleled in an exact fashion by the science which places whales with the quadrupeds to which in their nature they are truly allied. For in all respects the whale is a "mammal," and in no sense is it a "fish." It finds a place and zoological home in the "class" which contains man himself as its highest representative; and it is thus separated by an infinite zoological difference and distance from the true fishes, with their gills and their purely aquatic existence. The whale is simply a mammal fitted for life in the water, just as the bat is a quadruped adapted for existence in the air. And the whale is no more to be regarded as a fish than the bat is to be considered a bird; or with any greater reason than a volume of poems should be placed beside a treatise on zoology because in size and appearance the two books present a close likeness.

On what principles, it may be asked, may we construct the "natural" classifications the advantages of which, as truly expressing the relationship of living things, have just been pointed out? It is perfectly evident that, in the artificial system of classification, the nature of the objects classified is decided by an appeal to outside look and external characters alone. Appearances, the deceptive character of which is matter of proverbial remark as applied to the affairs of ordinary existence, are as untrustworthy, if not more so, in the scientific discrimination of animals and plants. Hence the advantage of the "natural" system of arrangement solely depends on the plain fact that we classify objects by this latter method, *through a true and exact knowledge of the things which demand our attention.* The whale is thus classified with the quadrupeds because, from an examination of its structure, we discover, at once, its affinities with mammals and the differences which separate it from fishes. The cactus is known to be an utterly different plant from the euphorbia, because our examination of the structure of both has plainly revealed the gulf which is fixed between them. The frog, formerly supposed to be a "reptile" (and still in popular natural history included in the reptile class), is known scientifically to exist outside the boundaries of that division, because its structure and life-history are those of no reptile known to us.* To classify anything, books or animals, exactly—to declare their true relationship—is thus an art the successful practice of which depends on our previous preparation in the facts of their nature, that is, in the case of living beings, of their structure and physiology. Thus classification may be defined as an expression, in a convenient form, of the facts and

* "Science for All," Vol. III., pp. 145 152.

laws revealed by a study of the structure and the functions of living beings.

Such is a brief explanation of the main principle which guides us in the construction of modern systems of arrangement of the animal and plant worlds. It follows from the declaration of that principle that, in arranging animals and plants, our first duty is to investigate their nature as accurately and exactly as possible; and upon such knowledge we may proceed thereafter to allocate our zoological possessions and belongings in definite and exact array.

The method according to which the animal world is classified, may best be understood by selecting a single animal form, and by showing how the place of that form in the animal series is ascertained, and how the relationship of the being to its near and distant neighbours is determined and expressed by the zoologist. As a preliminary study, we may map out the animal world in the following fashion; and the plant world, it may be added, follows in its arrangement an essentially similar method:—

Kingdom.
Sub-Kingdom, or Type.
Class.
Order.
Family.
Genus.
Species.
[Variety.]

This table indicates briefly that the whole animal kingdom is primarily divided into "sub-kingdoms;" that each sub-kingdom is parcelled out into "classes;" each class into "orders;" each order into "families;" each family into "genera" (singular, "genus"); and each genus into "species;" whilst the species, in their turn, may exhibit "varieties."

Now the method by which we settle the place of an animal in its series is exactly that by which we would determine the place of habitation and relations of an individual whom we do not know, but whose acquaintance, intimate or remote, we are anxious to make. Imagine, by way of practical illustration, that a supposititious Mr. Alfred Smith, of Bold Street, Liverpool, is the object of our search. We proceed, it is true, directly to Liverpool and to the thoroughfare just mentioned as the result of our inquiries; but in such a proceeding we really perform a series of mental operations which have for their aim the separation of the Mr. Smith from all the rest of the world. Although we do not actually say that the person in question inhabits the world, the Continent of Europe, and in turn Great Britain, Lancashire, Liverpool, and Bold Street, we tacitly assume all of these propositions, because the latter facts—those of his residing in Liverpool—actually involve all of these considerations. In determining the place of an animal in the scale of classification, our procedure is essentially similar to that just noted. We begin primarily by assuring ourselves that it belongs to the animal *kingdom*—a fact not difficult of discernment as a rule, but the determination of which, in the case of many low organisms, might present a puzzle of exceeding complexity, or one even impossible of solution. But, laying aside the difficulty of settling whether a given organism of low type is an animal or plant, we next determine its exact place in the "kingdom" by a series of investigations strictly comparable to those whereby we give to Mr. Smith "a local habitation and a name."

Suppose, by way of illustration, that the subject of our inquiries is a horse, and that, in the guise of an unknown animal form, this familiar quadruped presents itself for arrangement and classification. We should firstly, after placing it in the animal kingdom, proceed to investigate its "type" or sub-kingdom, just as in the case of the unknown personage, Mr. Smith, we should localise broadly his exact geographical situation in the world. To ascertain the sub-kingdom or type to which the horse belongs is much the same thing as determining that Mr. Smith inhabits the Continent of Europe. Such information might at first sight appear of hardly any value, but a little consideration would show that in this primary fact we limit the personage to a certain area of the world. That area may be very wide and extensive, as it undoubtedly is; but it nevertheless determines certain broad and general facts of his existence, and it moreover shuts out of view and consideration all the other great tracts of the earth's surface. So with our horse. If we place that animal in the "sub-kingdom" *Vertebrata*, we determine its "continent." We place it, in other words, in a large group of the animal world, in which it is lawfully associated *with all those animals that agree with it in having their bodies built up on the same fundamental plan.* To say that a horse, then, is a "vertebrate" animal is to allege that its body exhibits an essentially similar and general plan to that on which the bodies of (1) fishes, (2) amphibia —frogs, &c., (3) reptiles, (4) birds, and (5) mammals or quadrupeds, including man, are constructed. Such information, although wide and general, is exceedingly important, because it not only shows us that there exist great types or plans of structure

in the animal world, but also demonstrates for us the horse's general place in the great array of animal life.

With our individual whose residence we are anxious to discover, the next step would be to determine his "country." The "country" of our horse is the special province of the Vertebrate group which it may be found to occupy. As a "country" is common to a large number of individuals who in general characters may be supposed to present a strong likeness, so the province wherein the horse resides must be marked by analogous likeness in its tenants. It is clear thus that our horse cannot claim any but the broadest likeness with fishes, amphibians, birds, or reptiles, whilst it is equally plain that he claims and obtains full recognition as a "quadruped." Thus we settle the question of his "class." A sub-kingdom is divided into "classes," the classes being merely divisions in which the general type of the sub-kingdom becomes more or less specialised. Thus our horse falls into the "class" *Mammalia*, and agrees with all other "quadrupeds" (from the kangaroo, whale, sloth, armadillo, up to dogs, cats, bats, beavers, apes, and man) because, amongst other features, it has never more than four limbs; because its jaws are parts of its head; because it breathes by lungs; because it is warm-blooded; and because its young are born alive and nourished by means of milk. Thus, as by saying that Mr. Smith is an inhabitant of Great Britain we eliminate from consideration all other countries of Europe, so, by saying the horse is a mammal or quadruped, we separate it from all other classes of which the vertebrate type is composed.

The next step in our determination of Mr. Smith's residence would consist in our fixing the special division of the county in which he is located. In France we should look for his "department;" in Switzerland for his "canton;" in America for his "state." In Great Britain we may parallel these examples by saying that the tract or area known as England is the special locality to which we should confine our inquiries. This procedure in the case of the horse would be that of determining its "order." As in Great Britain we have various kinds or races of Britons, or as the land in another way is broadly parcelled out into three chief divisions each of which is marked by its own special national peculiarities, so in the animal world, with all "quadrupeds" as a class before us, our duty is that of saying *what kind of quadruped* the horse may be. To say that the variety of quadrupeds is immense is to state a commonplace truism. In a group wherein forms so diverse as a whale and a bat are included, it is absolutely needful that the work of classification should next proceed to parcel out in "orders" the varied array of the quadruped class. A casual inspection of our horse reveals that it has four well-developed limbs, and that it possesses largely-developed "nails," in the form of "hoofs." Now these characters alone, not to mention any further and accompanying features, determine for us the "order" of the animal. As Mr. Smith, by being located in England, would be named an Englishman, so the horse, by the possession of the characters just mentioned, appears before us as a member of the *Ungulata*, or "hoofed" quadrupeds; and at this stage it will be seen we have succeeded already in limiting considerably the range of our inquiries, whilst we are drawing nearer and nearer to the horse as an "individual."

"Orders" are divided into "families;" and, although the latter term in zoology and botany indicates a wider sphere of relationship than when used with reference to human connections, the personality of its included members will be found to be fairly well defined when the "family" characters of any group of living beings are scientifically determined. The "family" in natural history corresponds roughly to the "county" of our fictitious Mr. Smith. By localising that personage in the county of Lancaster, we should thereby determine his personal history in a tolerably exact degree. Assuming, for the sake of nearer parallel with the zoology of the horse, we might reasonably enough take that statement to imply the existence of special personal characters—just as, to localise another person as a native of Aberdeenshire, would be tantamount to saying that peculiarities in dialect and in other respects might determine his special locality and race. The horse, when merely placed in the "order" *Ungulata*, is found to occupy a division in which "hoofed" animals so diverse as hippopotami, rhinoceroses, camels, pigs, tapirs, giraffes, deer, &c., are included. When, however, we proceed to allocate these animals to their respective "families," or divisions, into which the order *Ungulata* can be divided, the special characters of each group become more or less apparent.

In the case of the horse, the family characters are very distinct. That animal (along with zebras and asses) walks upon the one fully-developed toe —the third—of each foot, this toe being protected by a very broad nail or hoof. We also find that two rudiments of toes (the second and fourth) are

represented in these animals in the "splint bones" of the leg. Then, also, the teeth are peculiarly arranged. There is a great gap or interval between the front teeth and the grinders; and whilst the males possess *canines*, or "eye-teeth," these are absent in the female animals. A horse possesses in each jaw six front teeth, or incisors, two canines (in the male), six premolars or bicuspids, and six molars or grinders, making (in the male) twenty teeth in each jaw, or forty teeth in all. The family characters may be summed up by saying that the horse's stomach is not adapted for "rumination" (*i.e.*, chewing the cud); and whilst the skin is hairy, a prominent "mane" is also developed.

So much for "family" characters, which leave us with horses, zebras, and asses as the three chief members of an interesting "family circle." The "family" in zoology is divided into *genera*. A "genus" may be compared to a person's town. Mr. Smith's town, Liverpool, would represent his "genus" in our parallelism; since, when we fix his residence therein, we place his personal history within a very decided limit. In the case before us, our task is now to separate the horse-genus from that of the asses—since the zebras are regarded as falling in with the asses to form, from their near relationship, a single genus of animals. To say that a horse is very readily distinguishable from an ass, is to remark in this case that the genus of the one animal is distinct from that of the other. The horse-characters are seen in the fact that the body is not banded or striped, and no dark line marks the spinal region. These characters are present in the asses and zebras; and whilst the horse has "warts" or horny growths on both fore and hind legs, the asses and zebras possess "warts" on the fore-legs alone. The tail of the horse, lastly is bushy, that of the asses being tufted. Thus we place the horse in the genus *Equus*, and the asses and zebras form a different genus named *Asinus*.

Genera in zoology, are divided into "species" —a word very familiar even to non-technical readers, and which is perhaps translated best by the English word "kind." To speak, in strict significance, of the horse and its "kind," would be to denote all horses merely, and to leave out of consideration the asses and zebras. In our work of localising Mr. Smith, the fixing of his exact residence in Bold Street, would correspond with our determining the exact place and range of the horse's species. When we discuss an animal's "species," we are tacitly considering itself and its own kith and kin, and we are brought face to face with the details of its personal history. Laying aside all questions considering the limits of species, we may say that any species of animals (or plants) is simply a group, containing these animals which are so much alike that we might regard them as the offspring of the same parents, whilst their progeny in turn will perpetuate the same intimate degree of likeness. Every horse repeats in greater or less exactness the features of its parents: every dromedary we naturally expect to be born with the single "hump" of its parent: every African elephant we expect to possess the large ears of its kind, just as the Indian elephant will appear with relatively small ears. Thus a close, or humanly speaking, a "family likeness" is the test of animals belonging to one and the same "species." And this latter thought leads us to the last term used in "classification," viz., "varieties." It might be necessary to localise Mr. Smith's position in Bold Street, accurately and exactly. This task we should effect by numbering the street, and fixing the site of our friend's dwelling-place by a numerical indication. Similarly in the animal world it is occasionally necessary that the "variations" or changes, which the animals of a species occasionally exhibit, should be duly noted. Thus, for instance, when we discover animals so apparently diverse in appearance and form as a dray-horse and hunter to be included under the term "horse"—or quadrupeds so different as a terrier dog and a mastiff to belong to the same "species"—the question arises, Do these animals represent different "species," or are they merely "varieties" of one species? The answer to this question is not always easy to furnish; but in the case of our horses and dogs, there seems little reason to doubt that the varied breeds of horses and dogs are true "varieties," and not distinct species. There is only one distinct "species" of living horse recognised by zoologists —the *Equus caballus*—and from this form we may presume the various breeds and races now represented have descended, through variations, some of the causes of which are known, whilst many causes are wholly undetermined.

We have thus traced a single being from amidst the great host of animals downwards to its own home and place in the kingdom, so to speak, by a step-by-step process of separating it from its fellows. In this process we gradually eliminate, with increasing force as we proceed, those beings which are unlike the special form we are engaged in discussing, until we arrive at that stage—seen in the "species"—when we find it impossible

to separate individual from individual. We thus, throughout the whole of our researches, trust, firstly, to a knowledge of *structure* as teaching us the true relationship of living beings; and we, secondly, starting with broad likenesses and general agreement in structure (as seen in comparing a horse with a fish), arrive in time at a stage when exact and intimate likeness introduces us to the veritable units of which the animal world is composed, in the "species." Our task of finding likenesses and discovering differences between animals, and of constructing a true classification of living beings, might thus be compared to our glance down a long vista or avenue. At the far extremity of the prospect, the avenue broadens out into a wide arena; just as when we regard a great group or type of animals (such as the Vertebrates), our view is of wide character. But as the eye traverses the avenue to our own standpoint, the vista narrows, until our perceptions of the objects near us are of intimate and minute kind. And so with the classification of living forms. The nearer we come to the individual, the more closely do we scrutinise features, form, and structure; and the broad likenesses which served us at the begining of our task, become lost in the individual history which we at last investigate, and which in reality represents the focus of our zoological researches.

SCIENCE FROM PENNY TOYS.

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We have before us a collection of cheap toys, such as can be bought in the streets of any large city. None of them cost more than a penny, yet they can, if properly used, illustrate many of the principles of physics quite as well as more expensive apparatus. Here, for example, is a number which we can employ in illustrating several points in mechanics; another section will aid us in understanding various questions in hydrostatics and pneumatics; while others will do the same for the properties of sound, light, heat, and magnetism, to say nothing of the fragments of chemistry and geometry that may be learnt from the same sources.

It will perhaps be better for us to begin with the series of toys that will help us with some of the laws of mechanics. The series of penny tops is a very large one, from the peg-top up to the humming and gyroscopic top; but these have already been described in another paper.*

Among the mechanical properties of bodies, that of elasticity is well illustrated. We have "Jack-in-the-box," the "jumping nigger," and the "hopping frog." In the first we have a spring of steel wire concealed. When the lid is on the box the spring, which is wound in a coil, is under constraint, but it is at once released on raising the lid, and with the energy thus set free out comes the figure. We make use of this same kind of spring, *i.e.*, coiled steel, in the buffers of railway carriages to prevent them coming together with too great a shock. Toy guns have a similar kind of spring, in which the strength is regulated to the size of weapon, and this determines how far the missile will be carried.

The jumping frog and jumping mouse vary somewhat from the other two. Under the figure a double cord is stretched, and twisted by means of a short piece of stick, which acts like a lever with unequal arms. The long arm of the lever is held to the under part of the frog, near the head (Fig. 1), by a piece of wax; the stiffness of the wax pulls against the tendency of the twisted cord. The continued pulling of the cord overcomes in a short time the adhesiveness of the wax, the lever is suddenly set free, and with a jerk sends up the frog into the air, giving it the appearance of a jump. It is therefore an instance of stored-up energy.

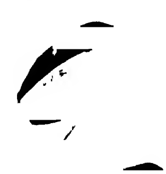


Fig. 1.—The Jumping Frog.

The penny scales furnish us with a good example of the simplest of the mechanical powers, for it is an instance of the first kind of lever. It is also a lever of equal arms. If the beam is fairly made, it will still hang horizontally when the scales are removed. According to the common idea of "centre of gravity," a rod of metal, such as this beam really is, should remain balanced in any position; but this does not, for tilt it up on one side, and it

* "Science for All," Vol. III., p. 153.

comes back to the old position immediately it is set free. It acts thus because its point of suspension is above its centre of gravity, for it is a law of physics that when a body is free to move its centre of gravity always comes to the lowest position.

Our scales have no "knife edge," but they will help us to understand how much better able they would be, if they had such an edge, to appreciate the smallest fraction of greater weight on one side than on the other. For if we had the centre of the beam turning on the sharp edge of a hard triangular piece of steel, and this resting on a plate of agate, we can see how delicate a balance we should have. Again, by increasing the length of the beam we increase its delicacy in turning at the slightest increase of weight on either side. Here we have also the means of showing how parallel forces act. Weight which is entirely due to gravity is overcome by a force equal to it pulling in the opposite direction. By this means, therefore, we use it for supplying certain standard quantities of commodities. A fixed weight is put into one scale, the article to be weighed is put into the opposite till it balances the standard weight. If the scales are accurately adjusted the substance weighed will balance the standard weight in either scale; but supposing it does not, as frequently happens in better-made scales than those purchased for a penny a set, the true weight may even then easily be told. For example, supposing a substance apparently weighs 5 lbs. in one scale-pan, and apparently only 4 lbs. when put into the other. What we have to do is to multiply the two weights (4×5) together, and take the square root of the product ($\sqrt{20} = 4 \cdot 5$ lbs. nearly) which will give us the true weight of the substance.

Fig. 2.—The Dancing Sailor.

A "dancing sailor" (Fig. 2) will illustrate a law which we call the "law of virtual velocities." A slight examination of this toy will show that the rapid movements in the "sailor's" legs depend on the rapidity with which the upper wheel turns. This wheel works on an axle, which is of hard metal, so that the friction is comparatively small. The outer axle is hollow, and with the larger wheel it forms one piece; to the circumference of the outer axle a string is attached, and by winding it round and pulling it sharply, the wheel is put into rapid motion, and the raised ridges on the upper surface of the wheel just touch the loosely-jointed limbs of the figure, which in consequence appears to dance. But our little machine is really a wheel and axle, or perpetual lever. The power being applied to the circumference of the axle acts at the short arm of the lever, the centre of the axle being the fulcrum. As employed it is a third form of lever, the power being greater than the weight. Now if the radius of the wheel—that is, the distance from the centre to the "periphery" or outside—is six times that of the axle, the force applied at the cord must be six times what it would be if applied at the radius of the wheel to do the same work. The circumference of the wheel moves six times as fast as that of the axle, and thus the rapid motion of the wheel is provided which is necessary to make the toy effective; so what we lose in expenditure of force we gain in the speed of the wheel. This toy helps to demonstrate the effects of inertia on masses of matter, for the heavy wheel having been put into rapid motion by the cord, it goes on till checked by the cord which it winds in the opposite direction. It must be borne in mind that motion is quite as natural to bodies as rest, and that matter by itself has no power whatever of altering its condition from one state to the other.

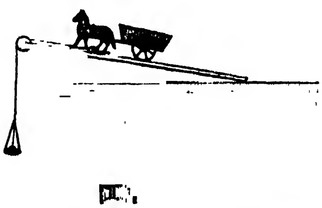


Fig. 3.—Experiment with Toys, illustrating the balance of forces.

The various toy vehicles will help us to test the application of another of the mechanical powers—the inclined plane—in an interesting manner. The metal horses and carts are the best for this purpose, because they are not only wonderfully well made, but they turn on their axles with very little friction. There is required, in addition to the toy, a thin slip of wood, say twelve or eighteen inches long, and a block of wood which will enable us to raise one end. Attach to the fore-part of the toy a thread, and pass it over a small wheel having a groove in its circumference—this can be made with a penknife—and attach to the end of the cord a circular piece of card to act as a scale. The whole will then be as shown in Fig. 3. To test the principle of the inclined plane, the toy, if drawn to the top, and left, will run down backwards. Suppose the plane—which we suppose to be 12 inches long—is raised, so that at one end it is 3 inches above the

table: then, whatever be the weight of the toy it can be sustained by $\frac{1}{4}$ of its weight; if you now drop it one inch it will be sustained by $\frac{1}{6}$ of its weight, but if raised to 4 inches it will require $\frac{1}{3}$ of its own weight put into the scale, to keep it in equilibrium. We get this rule fully established: that "the power is to the weight as the perpendicular height is to the length of the plane." This law applies to all methods in which the inclined plane is used under these conditions.

The next series of toys are dependent on the mechanical properties of air: this they all illustrate exceedingly well. We take a common leather sucker: it is moistened, then pressed closely to the surface of a stone or some other object; the air being thus shut out from between them exerts a pressure,* so that a stone may be lifted or a door may be opened by means of the sucker. This air-pressure, which averages 15 lbs. per square inch, is also illustrated by the squirt. The tip is dipped into water and the solid plug inside raised, making a partial vacuum—it would be a complete vacuum if it fitted the barrel quite accurately—in the barrel; the outer air presses on the surface of the water, which is raised, and fills the barrel; this, on being lifted, bears with it a charge of the liquid. The plug is next forced in the opposite direction, and exerts a pressure on the liquid, which consequently all endeavours to escape at the same time. The water is thus forced a considerable distance. The hydrostatic law "that liquids transmit pressure equally in all directions" is clearly demonstrated. The coloured balloon shows the air to be a substance possessed of elasticity. By putting it in front of the fire it increases in bulk; take it to an ice-cold place, it decreases considerably. The air is thus proved to be elastic, and its bulk readily shows an increase or decrease in temperature.

The pea-shooter is another example of work done by the elastic force of air. The pea or other missile is put into the tube, the trumpet end of which is placed so that it is securely closed by the lips, then a sharp puff is given. The air in this condition is really imprisoned, it tries to get free, and in doing so strikes on the pea, driving it out to some considerable distance. The pop-gun is a further illustration of the elastic force of air. A quantity of air is enclosed between the two pellets, and when one is pushed by the rod, which is really a piston, the imprisoned air is compressed more and more till at last it overcomes the resistance offered by the pellet in the fore-part of the barrel. The "diver imp" is another illustration of the same principle. It sinks when pressure is put on the top, because the bubble of air in the figure becomes denser, and therefore heavier: when released it rises. The shuttlecock, kite, and flying top are further proofs of the materiality of the air, and also help us to understand the joint influence of two forces acting at the same time on the same body. The action of the kite will help us to explain this law which, according to Sir Isaac Newton, is one of those effects due to the second law of motion. Take a rough illustration first. If a small block of wood be laid on a flat surface, and be drawn along that surface by a piece of string, it will follow the direction in which it is drawn; but while this force is at work let it be pulled by a second piece of string, at right angles to the first piece, the wood will now follow the direction of neither one nor the other, but will go between them. If the forces are equal it will go equally between them, forming the diagonal of a square. This understood, we have the key to the flying of a kite. Let a b (Fig. 4) be the kite, with the string attached to what boys call the "belly-band" at about one-third of the kite's length from the top. By pulling the string the buoyant power of the air lifts the kite and causes it to float. By pulling it in a direction towards yourself a wind is raised which tends to take the kite in the opposite direction, as shown by the arrows. This has a tendency to lift the kite, and produces what we call pitching, which freak is prevented by the addition of a tail, proportioned to the weight of the kite. In Fig. 4 the arrows in the horizontal direction show the direction of the wind in which the kite has a tendency to proceed, but the pull of the string tilts the top forward, so that it thus floats on the air. Gravity has another influence on it in a downward direction. If the string were cut, this would soon have the mastery, and the kite would quickly fall to the ground. The two component forces acting on the kite are gravity and the wind, and the string acts as the resultant of these two separate forces. The same principle is illustrated by the shuttlecock

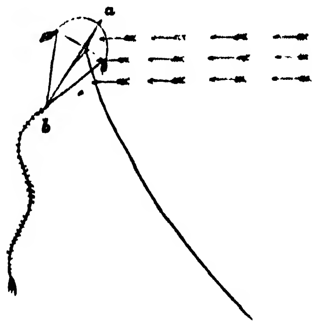


Fig. 4.—Experiment with Kite, illustrating one of the laws of Motion.

* "Science for All," Vol. ., p. 103.

in its flight and direction as it is struck from one battledore to the other. The flying top ascends and descends through the air in a slanting direction for exactly the same reason.

Another series of toys depend on a different class of properties. For instance, we have the penny whistle, the Pandean pipes, the shrill dog-whistle, "the bird-warbler," and other such musical toys. Many of the principles of sound, and the difference between music and noise, can be clearly illustrated by these simple instruments.*

In order that sound may be caused, three things are necessary. (1) There must be a vibrating body; (2) there must be a carrier or conductor of these vibrations; then (3) there must be the receiver of the vibrations, which is the drum of the ear. To illustrate this, take an experiment that almost every boy has tried at some time or other. Supposing he has bought a bun, which is generally wrapped in a bag; after he has done with the bag, he inflates it by blowing into it. Holding it tightly by the mouth, he gives it a smart blow with his other hand, and bursts it with a loud explosion. In this we have the enclosed air suddenly compressed by the blow and as suddenly released; this sets the air in the vicinity of the bag in a violent state of vibration, which it communicates, by means of the surrounding air-particles, to the ear. This is called a noise, because of the irregularity of the vibrations; if the vibrations take place regularly, music is produced. In regard to conductors of sound many substances are better conductors than air—such as water, wood, metals—but air is the general and universal conductor. The average rate at which sound is conducted by air is 1,090 feet per second. Remembering this fact, we can tell how far a thunder-cloud is distant from us by observing the time that elapses between the flash and the thunder-clap.

A "whistle" is an instrument fitted to vibrate a column of air. The dog-whistle is very short—it gives out, therefore, a very shrill sound; the tin whistle is larger, and is therefore less shrill. Long strings and long columns of air when in a state of vibration emit lower notes than shorter ones. Other things being the same, the pitch of the note depends on the length of the column. An examination of any musical instrument like an organ or pianoforte will convince us of this, and so will a penny whistle.

If our whistle is what is called a "C," it will give this note when every hole is closed and it is not too sharply blown. Its note will correspond with that of a "C" tuning-fork, but it will be what is called an octave higher. †

As the rate of vibration is determined by the length of the column, and *vice versâ*, if our whistle gives a note out an octave higher than our tuning-fork it necessarily vibrates twice as quickly. A "C" tuning-fork is known to vibrate 256 times per second; the air-column in the whistle therefore vibrates 512 times a second. Suppose we get C with all the holes closed: now blowing with the same force, let the finger be raised from the lowest hole, and we get one note higher, or D; if this column is measured, it will be found to be $\frac{8}{9}$ of the length of that which gave C; raise another finger, always reckoning from the lower end, and we get E—this sounding column will be found to be $\frac{4}{5}$; by raising the next finger we get F, with a column of $\frac{3}{4}$; next G, with a column of $\frac{2}{3}$; next A, by $\frac{3}{5}$, and next B, by $\frac{8}{15}$; next C, by all fingers down, but blowing with double the energy. This sharp blowing breaks the column up into two parts, or the columns each become half their former length.

In organ pipes the open tube gives a note exactly an octave higher than the same tube would do if closed. The wooden whistle and tin whistle help us to understand what is meant by *quality* of tone. Both instruments admit the air through a small slit at the mouth, which is met by a sharp lip; it is by impinging upon this that the column is set into vibration.

The same column-lengths give the same note, but the wooden instrument gives a less shrill note, and different in quality to the metal. Thus all instruments have their own special qualities, distinguishable from each other, according as they are reed, metallic, string, or membrane. These facts are fully illustrated by the Pandean pipes, in which perhaps the column-lengths can be better studied. The reed-pipes of the organ give out a much more mellow sound than the metallic.

Another toy musical instrument is the old-fashioned Jew's-harp: this seems to be an especial favourite in some districts where penny toys are sold. In this toy the different notes—high and low—are caused by varying the pressure of the air from the mouth upon the tongue of the instrument, and not by alteration in its length, as in the others we have named. The difference of length is here made up for by differences of pressure. A short string stretched tightly gives out a high note, as we have already said; but if we load this string by twisting another round it so as to thicken it, it gives a correspondingly lower note.

* "Science for All," Vol. I., p. 124.

† "Science for All," Vol. II., p. 296.

So with the tongue of the Jew's-harp; each note it gives out is determined by the greater or less compression with which the air is blown on to it, and by the shape of the mouth, which determines how much air is set vibrating with it.

An ordinary drinking-glass will give out a sound when struck, or when a violin-bow is drawn across its edge. By suspending a piece of cork attached to a thread, so that it touches the side of the glass, it will be put into violent motion, immediately sound is emitted, owing to the vibration of the glass.

By covering glass plates with fine sand, and clamping them tightly along one side, and drawing a violin-bow along the opposite edge or at one of their corners, the sand is found to arrange itself in regular forms. The beautiful figures thus produced are known as Chladni's figures.* If some sand be sprinkled on a drum-head or on the face of a tambourine, and a tuning-fork, bell, or other sounding body be struck near it, the sand is at once affected in a similar manner. This shows how sympathetic vibrations are.

We have next a series of marbles. Let a row be arranged, containing about sixteen, so that they all touch. Now draw one out from the rest; run it sharply back; immediately it strikes the first of the series the last, but the last only, flies out from its place. Repeat the experiment, drawing two this time, and driving them back to their places with a smart blow; immediately they come in contact with the series two will be driven out. This affords us an excellent example of transmission of force, for the effect of the blow is carried on from one end of the series to the other—almost in an instant—and the last flies out because it has nothing to which it can give up its force; it is therefore set in motion by it. It helps us to understand Newton's first law of motion—viz., that a body remains at rest, unless a force is impressed on it; then it moves in the direction of the force, and to a distance proportional to that force.

Picturing to ourselves particles of air arranged as these marbles are, we conclude that the sound is conducted through the series in as short a time and in a similar manner, till it comes to the end of the series, the last of which strikes the drum of the ear, setting it vibrating. The elastic marbles roughly illustrate what really takes place with elastic air-particles, showing their alternate compression and expansion. But they are infinitely smaller by many millions of times. The penny telephone depends on the power that materials have for conducting sound. It consists of two ends, very like shallow pill-boxes without lids; through the bottom of each passes a piece of thin twine, the ends of which are knotted and fastened into the boxes. (See Fig. 5, Vol. I., p. 183.) An instrument of this kind is sufficiently good to carry sound distinctly for some thirty or forty yards. If a metallic cord be substituted for the ordinary twine, conversation can easily be carried on at a distance of two hundred yards.

It is said that in Ceylon the natives have for more than a century been acquainted with this method of conveying sound. This form of instrument must not be for a moment confounded with the Bell or Edison form of instrument,† for here the cord acts as a simple conductor of sound. The speaking-tubes employed in large buildings act on similar principles, the air-particles conveying sound just as the series of marbles transmitted the effects of the blow. Air when confined in tubes conducts sound much better than when free; water, however, conducts it about four times as fast as air; while an iron rod or even a deal stick carries it sixteen times as fast.

We will now turn to another toy which really could furnish us with material enough for an entire lecture. It is the "Tom Thumb magnet." It has the form of a horse-shoe—not very elegantly got up, it is true, nor is it of very fine temper; it has, however, the directive power which belongs to all magnets, and therefore, to all intents and purposes, acts as well as the best made instruments. Magnets are of two classes, natural and artificial. The Tom Thumb magnet belongs to the latter class. Very few are now formed of magnetic iron ore, which is the mineral from which they were first made; and as this was found in Magnesia, the property of this substance has been called magnetism. The artificial magnets are made from highly-tempered steel, which is magnetised either from a voltaic battery current, or by being rubbed against a natural magnet, or by another artificial magnet. Soft iron can be endowed with magnetic qualities, and will retain them as long as it is in contact with the magnet or under the influence of it, but immediately it is removed the magnetic power vanishes.‡

In what way does ordinary iron differ from a magnet? In substance there is very little difference, but when a magnet is suspended it persists in hanging in a certain direction.

Take, for example, any magnet, suspend it by a piece of silk; take an iron nail, soften it by heating

* "Science for All," Vol. III., pp. 91-2.

† "Science for All," Vol. I., p. 180.

‡ A fuller account of this is given in Vol. I., pp. 181-2.

it red hot, and bend it into the same shape as the magnet; when cold, hang it in the same way. The magnet will take a direction of its own, the nail will hang in any direction you please. The magnet has a mark filed across one of its arms; in the better class of magnets the letter N is marked on the same arm. Another difference between a magnet and an ordinary piece of iron of the same shape is that if the former be dipped into a mass of iron filings or a box of iron tacks, a mass of these will stick to it, while they will not be attracted by the piece of iron. It therefore has an attractive power for some substances: these are called *magnetic* substances. But a magnet repels as well as attracts, as may be shown by the following simple experiment. Take a steel knitting-needle, suspend it in a little stirrup of paper; present the marked end of the magnet, the needle will come towards it; present the other end, it will do the same. We will now take the needle and rub it several times across the marked end of the magnet, taking care that we rub it always in the same direction. Having done this, we replace the needle in the stirrup and present the marked end of the magnet to it. When presented to one end it will attract, but when presented to the opposite it will repel. Mark with a file the end repelled by the marked end of the magnet. Treat another knitting-needle in the same way, and you have a pair of bar magnets. Suspend the two needles as before by means of the thread and paper stirrup. not close enough to touch each other, but near enough to be under each other's influence. The needles will so arrange themselves that the marked end of one will point to the unmarked end of the other, and will arrange themselves in the same line. Now twist the needles round so that their marked ends come together; they at once repel, and arrange themselves as before. We are here taught one of the first lessons in polarity —viz., that like poles repel and unlike poles attract. Take a couple of sewing-needles, and rub them on the Tom Thumb magnet, place them afterwards lightly in a glass or a basin of water; they will at once arrange themselves as the suspended needles did. These needles we have made into artificial magnets, and they will probably retain their magnetism for some time.

If you had accurately measured your knitting or sewing-needle before magnetising it, you would find that it is actually lengthened after being magnetised. This serves to remind us of one of the effects of heat. We know that when we heat a metal bar it expands, but it increases in all directions, in breadth and in thickness as well as in length, but not so the magnetised bar—in reality it is a trifle thinner.

When you take the magnet or one of the needles, and cover it over with a sheet of paper and sprinkle on it a few fine iron filings, they all cluster about the ends of the needle. If you dip the ends into a quantity of iron filings the result is the same; they seem to have no tendency whatever to cling to the centre at all, for it remains quite bare.

From this, one would imagine that all the magnetism resided in the ends, but break the needle, and treat it as you did the whole needle, and you will find that the centre which had no attractive power before has now become a "pole" as powerful as the other. If you were to break it into twenty, or a hundred, or any number of pieces, the result would be the same: each end would be a "pole."

This polarity in the magnet gives it its directive tendency. The point marked N in our magnet points towards the earth's geographical north; the earth itself, being a magnet, must therefore have its magnetic south near its north geographical pole. It is very rarely that the magnetic pole and the geographical pole exactly agree. At the present time the former is about 18½° west of the latter; in 1663 they exactly coincided.*

As these variations, which take place from year to year, are known, it makes no difference whatever to the usefulness of the needle in its employment in the mariner's compass. This tendency of the needle west or east of the geographical pole is called its *declination*. The *dip*, as it is called, of the needle we can hardly show by means of our magnetised needle. With a delicately-poised needle this is readily seen. It is only at the equator that the needle hangs perfectly horizontal to the earth's surface, but in any place north of the equator its north pole points downwards, and in the southern hemisphere its south pole points downwards. This is what we call *magnetic dip*. It varies with its position on the earth's surface, being greatest near the poles and less as the equator is approached. We can illustrate it by means of our magnetised knitting-needle and a small sewing-needle. In Fig. 5, let *a b* be the knitting-needle and *c* the neutral point; a sewing-needle balanced and sus-

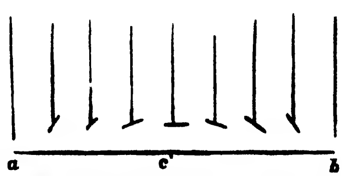


Fig. 5.—Experiment with Needles, illustrating the "Magnetic Dip."

* "Science for All," Vol. II., pp. 171—6.

pended over this point will be parallel to it; if brought towards a the needle tilts a little towards it; if brought farther still, it becomes more inclined; and so on till it gets to the end, when it will take the vertical position. If the end a happens to be a north end, the inclined end of the sewing-needle will be of the opposite character, and *vice versâ*.

Another series of penny toys illustrate very clearly some of the laws of light. We have, first of all, the drawing slate. It is semi-transparent, and on the upper side, which is rough, we make a tracing of the figure on the paper below. We are induced by the examination of this roughened piece of glass to inquire what causes transparency. We do not use such glass for windows, through which a good view is required, but we use clear glass, which is a much more transparent substance. If we take the glass out of the slate frame and wet it, we find that its power of transparency is increased; if we use turpentine it remains transparent for some time. Glass is not perfectly transparent: in fact, transparency is a comparative term; water is more transparent than glass, yet at the depth of a very few feet below the surface very little light penetrates. Air is still more transparent, yet it absorbs some light: thus we have the blue of the sky. A perfectly transparent substance should allow all the light to pass through it.

Many opaque substances will, under certain conditions, transmit light; gold-leaf, for example, if placed between two sheets of glass, allows green light to pass through; yet gold is the most dense of all familiar metals. We have among our collection of toys looking-glasses or reflecting surfaces, but these we need not describe, as the principles of reflection in mirrors have already been explained.* A distorting mirror may also be bought for the modest sum of one penny. This, on looking into it in one direction, lengthens the face considerably in appearance; at the same time it contracts it in breadth, thus ludicrously caricaturing the whole countenance. Turn it so that you look into it with its greatest length right and left, and the features are distorted in a like manner.

The magnifying-glass is another familiar toy, which can also be used as a burning-glass. In either case the light and heat rays are brought to a focus, and an object placed at this point, when rays are collected from a strong source of heat, may be set on fire. When used as a magnifier the rays coming from the illuminated object are refracted by the lens—which is either a plano-convex or double convex—thus increasing the angle under which an object is seen, this increase of angle depending on the convexity of the lens.

* "Science for All," Vol. I., p. 191.

A simple microscope is sold for a penny, consisting of a mere bead of glass mounted in a bit of cardboard, its principle being the same as that of the magnifying-glass. Its focal length is very short, so that it has to be brought close to the object in order that the latter may be viewed. Globular glass bottles are powerful magnifiers as well as very strong burning-glasses, so that in druggists' shops they have frequently become sources of mischief, and should be shielded from the direct rays of the sun by a light curtain or a sheet of paper.

The kaleidoscope, which was invented by Sir David Brewster, is a toy founded on some simple principles of reflection, and comes into our series of penny toys. It consists of a tube, generally of cardboard, and running through its length we have two slips of glass blackened on one side: they act as reflectors. At one end is a piece of plain glass, upon which pieces of coloured glass, beads, and tiny objects are placed, and over this a piece of ground glass is fastened, leaving sufficient distance between them for the pieces to arrange themselves loosely. At the opposite end a hole is provided, through which we can look when the instrument is held up to the light. The designs produced as the kaleidoscope is twisted round seem numberless. The image formed is shown in Fig. 6, which explains the various reflections. The observer on looking into the instrument sees a circle, with a diameter double the width of one of the reflectors, and this is apparently divided into six regular and equal spaces, two being direct reflections from the real objects, two the second reflections of each glass, the other two being the reflections from the glasses.

Fig. 6.—The Kaleidoscope.

We have still before us a number of toys, which would illustrate some further important principles of physics, but for the present we must leave them unemployed in the service of science. Still, so far as we have gone, we hope we have succeeded in

showing that such simple appliances as penny toys will fill other offices besides being mere playthings, and that in some cases numerous and striking experiments of an interesting and instructive character can be shown as completely by their aid as with much more elaborate apparatus.

COMETS.

By W. F. Denning, F.R.A.S.

Of all the phenomena which the heavens present for our contemplation one of the most imposing is a large comet as it spans the constellations with its wreath of flame, and traverses the sky with a rapidity of motion seldom to be witnessed. The unexpected apparition of so startling a visitor from the interstellar spaces, and the majestic aspect it assumes with increasing dimensions, are such as naturally fill the unlearned with awe, and we can easily understand the superstitious dread with which these objects were regarded in bygone generations, when

> "——the blazing star was viewed,
> Threat'ning the world with famine, plague, and war."

Occasionally a great comet would suddenly burst out upon the affrighted gaze of mankind, displaying a terrific appearance as it successively took up new positions and assumed a number of grotesque configurations. This was before the invention of the telescope enabled comets to be discovered at remote distances, and watched as they gradually approached the sun with increasing brilliancy. The light of science had not penetrated far into the deep mysteries of these bodies, so that they terrified mankind with their threatening aspect, and were looked upon as the bearers of malign influences—the ill-omened intruders upon the normal beauty of the sky. Little had then been learnt concerning them. Their erratic motions were perplexing in the highest degree, and gave rise to many wild theories which sufficiently demonstrated the prevailing ignorance. They came and they went, exhibiting singular varieties of appearance, and a diversity of motion in striking contrast to the regular movements of the other celestial bodies. Some of the ancient philosophers looked upon comets as merely the reflection of beams from the sun or moon; others considered that they were originated by luminous vapours or exhalations from the earth.

The visible character of a large comet renders it a special object of curiosity to those whose inclinations prompt them to seek knowledge of the most wonderful facts in nature. Indeed, the conspicuous appearance of such a body in the sky invariably attracts considerable notice, and is usually the prelude to many anxious inquiries from those who would catch a glimpse of the strange visitor. A newspaper paragraph generally gives the first public intimation of the discovery of a comet. But as a rule such notices refer merely to telescopic comets (Fig. 1), of which several are detected every year, and it is only in the comparatively rare instance of a bright comet that popular interest is fully aroused. Then the next starlight night is rather impatiently awaited by many people anxious to indulge their curiosity, and perhaps to gain a little notoriety from their personal friends as being the first to point them out "the new comet."

A fine evening draws in, and our intending observer, having carefully assured himself that he has correctly interpreted the description of the comet's place, begins to scan the sky in the suspected region with a good deal of erratic vigour, long before the twilight has disappeared. Nothing is seen at first, and he begins seriously to doubt the alleged discovery until, as the darkness increases and the fainter objects in the firmament become perceptible, he distinguishes from amongst the host of stars a small hazy appearance, which is at once recognised as the body sought for, and it is promptly pointed out with no lack of enthusiasm and pride to such of his friends as are within call.

There is the comet, it is true, and the observers are much gratified at the view; but after the novelty of the first impression has departed they agree that really the spectacle is not *very* striking, and signs of impatience and discomfort soon become apparent amongst them, until a hasty retreat is made in-doors with apologetic expressions relating to the fear of taking cold.

But the interest of the earnest observer is not of the same fugitive character, and he remains to watch the comet and to note particularly its appearance and direction. Comparing its position with respect to a terrestrial object, he finds that it pursues the same relative motion as that of

the stars, and that in a few hours it will have descended to the northern horizon. It exhibits a decided train, which he notes flows upwards and becomes more diffuse and faint, until its extreme upper limits cannot be defined from the background of faint stars on which it is projected. The head, or nucleus, looks bright, something like a tolerably large star enveloped in haze or seen through a translucent medium, and its solitary aspect amongst the constellations lends a peculiar charm to the spectacle. Our observer, having satisfied himself on these points, determines to re-observe the comet on the first clear night ensuing, but cloudy weather intervenes, so that the sky is constantly overcast until nearly a week afterwards. Meanwhile the comet has undergone rapid changes in size and position, which almost prevent its being recognised as the same object. It has travelled over a large space to the westward, and is considerably larger and brighter than before. The train now extends over many degrees, while the nucleus has evidently intensified; but the comet soon sinks to the horizon, where its beautiful form is lost amid the gathering clouds. The next night it is seen again, when the observer is struck at once with the fact that it has further increased in dimensions, and that its motion is rapidly carrying it towards the sun. A few more nights, and it will evidently cease to be visible. As the observer continues to watch the comet during the short interval before its early setting, his mind becomes filled with thoughts as to the origin and end of the strange apparition. It has been increasing in size with startling rapidity, and rushing towards the sun with a swiftness of motion to which he can recall no parallel. What will become of it when it reaches the sun? Will it be volatised in the tremendous heat, or will its great velocity enable it to sweep past into the immeasurable depths of space beyond? Is the comet to be regarded as the "shining sword" of retribution—the emblem of ill—or as simply one of the ordinary phenomena of nature with its appointed course? Evidently it is a body of vastly different character and composition from the sun, moon, and planets, which display a regularity and harmony quite opposed to the erratic motions he has been observing, for while the planetary members of the solar system confine their orbital revolutions to the zonal region of the ecliptic, the comet has followed a path nearly at right angles to it.

When a comet is first discovered, it is usually a very faint nebulous object, without any decided traces of a tail (Fig. 1, *a*). It soon develops itself into a more conspicuous object (Fig. 1, *b*), giving signs of a nucleus, from which a faint train is gradually thrown off as the comet becomes better situated for observation. It approaches the sun with increasing velocity, and is lost for a time in his rays, soon emerging again on the other side, and undergoing diminution as it recedes into space. As a rule, these bodies are not within the reach of the naked eye, and they are watched merely by a handful of observers, habitually engaged in such work

a *b*

Fig. 1.—Telescopic Comets.

at public observatories. Comets are rarely discovered by accident; they are usually found by the systematic exploration of the heavens with a telescope of low power. Several foreign astronomers are wholly occupied every clear night in the work of sweeping the sky for new comets. When a suspicious object is brought into the field of view, its position is at once determined, and it is referred to a catalogue of nebulæ, for it is sometimes impossible to distinguish, as regards appearance, between a telescopic comet and a faint nebula. If its position is not identifiable with one of the numerous class of objects included in the latter category, it is closely watched for traces of motion, which must immediately become evident in the event of its being a comet. Its exact place relatively to several adjoining stars is carefully fixed, and after a short interval, the comparison shows a slight alteration in the observed positions, which at once settles the matter. The discovery is telegraphed to foreign observers, and subsequent observations of the comet enable the orbit to be calculated and its period determined if the elements are found to agree with those of a previously observed comet. But there are some difficulties in the way of fixing the true form of cometary orbits, because these bodies can only be watched while traversing a small arc of their paths, and the

larger invisible portion of the orbit has to be inferred from the visible portion. This occasions considerable difficulty, because several varieties of orbit are found accordant with the paths of these erratic and often unexpected visitors.

Cometary orbits are divided into three distinct classes—the ellipse, parabola, and hyperbola (Figs. 2, and 3). In some cases comets revolve in elliptical paths of various eccentricity, and reappear periodically, as, for example, Halley's comet, which returns to the sun at intervals of about 76 years, or, selecting one of shorter time, the comet of Encke, with a period of only 1,210 days (3·3 years). The elliptical comets represent, in fact, the periodical comets, for the character of their orbits proves that they must revisit the sun again and again at certain definite ascertainable periods, subject to some slight irregularities occasioned by planetary perturbations.

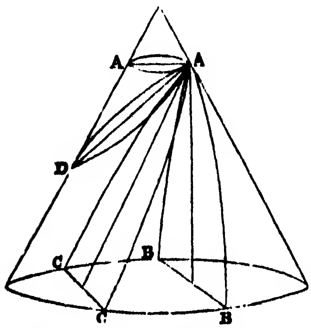


Fig. 2.– The Conic Sections.
(A A) The Circle; (A D) the Ellipse; (C A C) the Parabola; (B A B) the Hyperbola.

The parabolic form of orbit is, however, usually applied to represent the paths of newly-found comets, partly from the facility with which it is calculated, and partly from the fact that it best satisfies the observations. The parabola is an ellipse of indefinite length, whose branches unite at perihelion, but extend in parallel lines an infinite distance into space, so that no comet of this class can be regarded as periodical, because on leaving the sun it never returns again to perihelion. Sir John Herschel says, "The parabola is that conic section which is the limit between the ellipse on the one hand, which returns into itself, and the hyperbola, on the other, which runs out into infinity."

The hyperbolic comets are those following paths which, though uniting at perihelion, extend into illimitable space without ever re-uniting. The hyperbola differs from the parabola in respect of its branches, which are divergent, and not parallel. Very few comets have been found to pursue this form of orbit; the majority revolve in ellipses, and hence belong to our system. But in cases where the orbit is an hyperbola there is no such distinction, for, after visiting the sun once, the comet recedes into indefinite space, and is lost to us for ever.

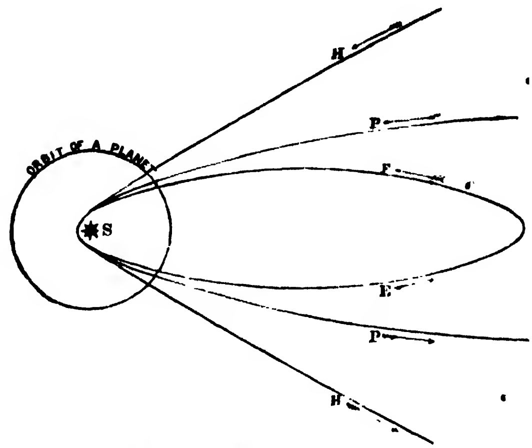


Fig. 3.—Diagram of Cometary Orbits.
(E) Ellipse; (P) Parabola; (H) Hyperbola; (S) Sun.

Indeed, that a comet belonging to this class is visible at all results from pure accident. Roving in space, they occasionally enter the region of the solar attraction, which soon makes itself appreciable as the comet is drawn towards the sun and wheeled around it with prodigious velocity, to depart again into space never to return. Such comets do not properly belong to our system at all. Like certain fireballs and meteors which have encountered the earth, they are purely sporadic in character, coming irregularly from the interstellar regions within the influence of solar gravitation, and rendered subservient for the time to its effects. At their nearest point to the sun (in perihelion) their distances vary considerably (Fig. 4). Like the first comet of 1847, they may almost graze the sun's

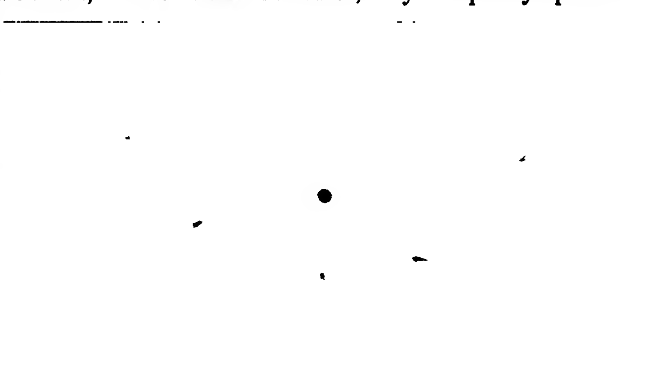


Fig. 4.—Successive Positions of a Comet near Perihelion.

surface, or never approach within the orbit of Mars, as in the case of Faye's periodical comet. The perihelion distance of the comet of 1729 was computed to be nearly equal to 400,000,000 miles, while that of comet I., 1843, was less than 550,000 miles.

Some comets appear wholly devoid of tails or of any nucleus indicating a condensation of materials; others show a very decided nucleus in the form of a luminous point situated in the densest region of the cometary vapour, and generally on the preceding side in the direction of the sun. Others, again, particularly in the case of large comets, show both a nucleus and train, which intensify and expand on approaching the sun. The nucleus is usually enveloped in an exterior nebulosity termed the *coma*, from the Greek κομή (*komé*), signifying hair. The comet of 1744 had six tails (Fig. 5), and, it is recorded, the intervening spaces were as dark as other regions of the sky. The comet of 1862 (III.) was not a very lucid object of its class, but it was chiefly interesting from the fact that it exhibited a series of singular luminous jets radiating from the nucleus and constantly varying in appearance.

The total number of comets which have entered our system, including those which properly belong to it, in past ages, is wholly beyond trustworthy calculation; but it is certain that a vast swarm of these bodies must have visited our region of space, the great majority of which were never visible to the human eye. Some would not approach sufficiently near the earth to be detected, others would be too small for inspection, and others again would elude discovery. In the three years 1877 to 1879 no less than fourteen were detected, though in the two preceding years (1875 and 1876) a remarkable lull occurred in the progress of cometary discovery, there being an absolute dearth of new comets between December 6, 1874, and February 9, 1877. The average annual number of visible comets is 3 or 4, though some years are more prolific than others, as in 1846 and 1858, which gave 8 comets each. The total number recorded up to the present time is about 850, and the rate of discovery is rapidly on the increase; for though, in the last century, the aggregate of such discoveries reached 71, the number for the present century (up to 1879) already exceeds 200. It will readily be understood that, before the invention of the telescope, only the larger class of these bodies attracted attention; thus the number of comets observed in modern times vastly exceeds those of ancient periods. Moreover, with increasing numbers of observers and improvements in astronomical appliances, it is certain that future years will yield a rich harvest of such discoveries. It is much to be hoped that some of the British observatories will devote a share of attention to this department, seeing that not a single new comet has been discovered in England during the last quarter of a century!

Fig. 5.—Six-tailed Comet of 1744.

The comets of short period, whose returns are capable of definite prediction, are essentially objects of considerable importance. They are apparently grouped into distinct families, with aphelion distances just outside the larger and more distant planets. Thus the Jovian family consists of a number of comets having periods of about five or six years, including the periodical comets of Brorsen, Winnecke, Biela, &c. The comet of Peters (1846, VI.) and of Tuttle (1858, I.), with periods of about thirteen years, revolve in orbits extending beyond the path of Saturn. The comets of Tempel (1866, I.) and Stephan (1867, I.) have

their aphelia near the orbit of Uranus, with periods slightly exceeding thirty-three years; while those of Halley, Olbers (1815), Pons (1812), and several others of the same group, give periods of between seventy and eighty years, and are, at their outermost points, more distant than the planet Neptune. In some instances periods of enormous length have been assigned to comets; thus the six-tailed (?) comet of 1744 was supposed to follow an elliptic orbit with a period of 122,683 years! and, like the second comet of 1844, having a theoretical time of revolution exceeding 100,000 years, can only possess interest for the historian.

The first of the periodical comets was discovered by the genius of Edmund Halley, and the chief facts concerning its history are very interesting. The large comet of 1682 induced him to investigate the subject of comets, and to calculate the elements of such of these bodies as had been sufficiently observed, with the view of finding some proof of periodical reappearances. His inquiries showed that the large comets seen in the years 1531 and 1607 moved in nearly identical orbits with the one he had observed in 1682, and he inferred that they were the successive apparitions of one and the same comet, revolving in an elliptic orbit, with a period of about seventy-five and a-half years. He predicted its next return for the end of 1758 or beginning of 1759, and, pursuing the question still further, detected historical records of other comets agreeing precisely in point of date with previous returns of the great comet of 1682. In the year 1456 a comet was seen "of unheard-of magnitude;" it had a tail sixty degrees long! In 1380 another comet was recorded, and in 1305 "a comet of terrific dimensions made its appearance about the time of the Feast of the Passover, which was followed by a great plague." In 1066 a large comet was seen, which "created universal dread throughout Europe, and was looked upon as a presage of the success of the Norman invasion." The returns of this remarkable comet have, in fact, been traced back to the year 11 B.C. by Mr. Hind, who has also identified from among the ancient Chinese observations many other apparitions of the same body. But the historical notices prior to the Christian era are too vague and imperfect to allow the returns of the comet to be traced back even further into remote antiquity. In 166 B.C. "a torch was seen in the heavens," but though the date agrees well with calculation, it cannot certainly be said to have been an appearance of this comet.

The predictions of Halley were fully verified. The comet was re-discovered on December 25, 1758, and remained visible five months. On May 5, 1759, its tail was forty-seven degrees long. In the autumn of 1835 it was again seen, but it appeared to have lost much of its ancient magnificent character. The year 1912 will probably witness its next return to our parts of space.

Of the comets of shorter period, that of Biela may be instanced as certainly the most noteworthy. It has a period of less than six years and three-quarters, and at its return in 1845 it was observed to divide into two distinct parts, which also reappeared in 1852, following parallel paths. Such a unique phenomenon had never before been witnessed; but another curious circumstance remains to be stated—viz., that this double comet appears, since 1852, to have wholly disappeared from our system! Repeated search has proved unavailing, and it seems a probable conjecture that it will never be seen again. Further divisions of its materials may have occurred, dispersing the original mass over a long range of the orbit, so that the only visible remnants of this singular body are occasionally seen as shooting-stars on the night of November 27, when the earth makes a very near approach to the comet's orbit.

Encke's comet of short period, observed by Pons on November 26, 1818, was found identical with one which had been recorded in 1805. Encke succeeded in computing the whole orbit, and found the period of revolution about 1,207½ days. The observation of this comet brought to light a marvellous fact in regard to its motion, which is slowly but certainly bringing it nearer to the sun and shortening its periodic time. If this continues, the comet must ultimately fall upon the sun. The laws of gravitation fail to explain so curious an anomaly. The disturbing forces of the planets are often severely felt by the thin materials of a comet, but in the present case these have been duly taken into account, and nothing remains but to attribute it to the effects of a resisting medium pervading space. Some physical agency, the nature of which is not exactly determinable, must constantly oppose the comet's velocity, and intensify the results of solar attraction in such a manner that the orbit is closing in upon the sun.

Newton held the opinion that comets were simply the aliment by which suns were sustained, and that such bodies, as they swept around their central luminaries, were gradually declining upon them. He said—"I cannot say when the comet

of 1680 will fall into the sun—possibly after five or six revolutions; but whenever that time shall arrive, the heat of the sun will be raised by it to such a point that our globe will be burnt, and all the animals upon it will perish." The light and scattered materials of a comet could hardly, however, give rise to so vast a conflagration, though the sun's light and heat would perhaps be greatly intensified in the event of such a catastrophe. The sudden outburst of light in the case of the temporary stars observed by Hipparchus (134 B.C.), Tycho Brahe (1572), and others, has been explained on the same ground.

The following is a list of the short periodical comets with which we are best acquainted:—

Comet's Name.	Period in Years	Next Return to Perihelion.
Encke . . .	3·30	1881
Winnecke. . .	5·55	1880
Brorsen . . .	5·58	1884
D'Arrest . . .	6·38	1883 4
Biela . . .	6·63	1885
Faye . .	7·41	1881

Though considerable importance is attached to these bodies, they are insignificant objects, and appear to be in process of wasting away, for at successive returns the same comets show decided evidence of decreasing brilliancy, and it has been conjectured that their materials are becoming distributed along their orbits, so that many of the comets will follow the precedent of Biela, and become wholly invisible when the central mass has been disintegrated and scattered into meteor orbits. That comets are liable to distortion and division when near their perihelia is a fact borne out by many historical notices, and it may be due either to the unequal attraction of the sun upon the several portions of the cometary cloud, or to the action of a repulsive force. In any case it is certain that the large area and unequal density of a comet as it wheels around the sun, passing, it may be, near one of the planets, is subject to many perturbations and disruptive influences which, frequently recurring, have the ultimate effect of sundering the original mass and extending it over a considerable arc, or, indeed, over the complete orbit, as in the case of the third comet of 1862, which gives rise to the annual display of August shooting stars.

The dimensions of certain comets have assumed extraordinary proportions; thus the great comet of 1843 had a tail 200,000,000 miles in length. There were two large comets in 1811, each of which exhibited tails of at least 100,000,000 miles. The comets of 1618 and 1861 each had visible tails extending over more than 100 degrees of the firmament, and it is extremely probable that these estimates are far below the actual figures, for it must be remembered that the visible portions of these bodies represent merely a condensed fragment of the entire mass, which is undoubtedly scattered over a far greater range of space. The nucleus of this condensation is sometimes very small and brilliant. The comet of 1811 (Fig. 6) had a nucleus

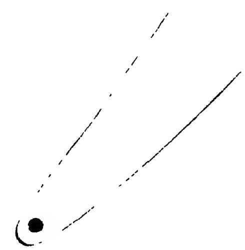


Fig. 6.—Great Comet of the Autumn of 1811.

only 428 miles in diameter, while the "coma" in which it was enveloped was calculated to cover 1,125,000 miles. The nucleus (Fig. 7) of Donati's comet in 1858 reached 5,600 miles, but the actual magnitudes have been found to vary with considerable rapidity.

These changes are due in great measure to the effects of solar heat and attraction, which must be severely felt upon the scattered particles of these bodies. Planetary perturbations are also to be taken into account, for in cases where a cometary

track falls near a planet there is reason to apprehend that the former is diverted from its original

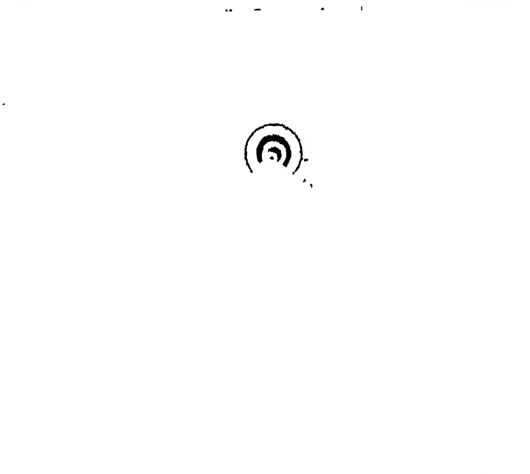


Fig. 7.—Telescopic View of Nucleus of Donati's Comet, October 2, 1858.

path. Such disturbing elements are always taken into account in calculations of cometary orbits and periods, as they are far too considerable to be disregarded. The planet Jupiter, from his immense mass, is eminently capable of influencing the motions of such comets as come within the range of his power; and, indeed, history contains a curious instance in which a comet wholly disappeared from our system, owing to its near approach to that planet. Lexell's comet, discovered by Messier in June, 1770, was computed, soon after its appearance, to revolve in an elliptical orbit, with a period of five years and a half; but this could not be admitted, as no such body had been observed in preceding years. In explanation of this anomaly, Lexell showed that in 1767 the comet must have passed close to Jupiter, and have sustained so great a shock that its orbit was entirely changed into the elliptic path derived from the observations in 1770; in fact, its incursion into our system was quite new, and wholly attributable to the disturbing action of Jupiter. Lexell also pointed out that in 1779 the comet must again approach the planet, and that probably its path would be converted into a parabola, in which case it would recede from us finally; and this eventually proved true, for the comet was never seen again.

Pons, early in the present century, was a most diligent comet-seeker. He found twenty-seven during the years 1801 to 1827; and, before him, Messier had been devoted to the same work, for between 1764 and 1798 he had discovered twelve of these bodies.

The duration of visibility in different comets is extremely variable according to circumstances of position and to the degree of inherent brightness. The comet of 1811 continued in view for 510 days, and those of 1825 and 1861 for twelve months each. Yet other instances might be adduced in which comets had been observed on one or two nights only.

Some comets are only visible in the northern hemisphere, others are confined to the southern, while in some cases they are seen in both hemispheres. A great comet was seen in the southern hemisphere early in February, 1880, with a train of some 40° or 50°, extending upwards, and curved

Fig. 8.—Telescopic View of the Nucleus of Coggia's Comet, July 12, 1874. (J. N. Lockyer.)

amongst the stars of Phœnix and Eridanus. On February the 7th, 1880, as seen at the Cape of Good Hope, the lower part of the tail enveloped the bright southern star Fomalhaut. It

unfortunate that the position of this fine and recent comet rendered it wholly invisible to observers in the northern hemisphere.

The physical nature of comets has offered some puzzling questions for theorists. It has been more than ordinarily difficult to account for the erratic behaviour of these bodies, and for the many curious forms which have been noticed in their appearance. But observation has at length accumulated a mass of facts regarding the visible aspects of these strange objects, which are of considerable value in such inquiries. It must, however, be admitted that the subject is still involved in mystery, and that the physical constitution of comets continues to present a problem of great complexity. The tails of these bodies, their comæ, the jets, fans, and aigrettes, are phenomena so utterly different to what is seen in other celestial bodies, that our conception fails to afford a sufficiently clear idea of the forces producing such curious results. It has been supposed that comets shine with an inherent phosphoresence, and are not rendered visible by the reflected light of the sun, for though some comets have exhibited bright planetary discs, no signs of phases have ever been evident. But this fact alone cannot be held to negative the point, because if a comet is understood to consist of an immense assemblage or stream of planetary atoms, then it is certain that the solar rays will be permeated amongst the whole mass, and it will appear luminous throughout the entire range of its denser portions. Every individual fragment will have its phase, which must, however, be entirely imperceptible at the distance of the earth, for the vast concourse of miniature pellets composing the stream is visible only as a mass. A little dispersion must place them wholly beyond our reach; indeed, in the case of some of the largest comets, we have been struck with the great tenuity and rarity of their material composition. They shine like a wreath of thin transparent vapour, through which the faintest stars are readily discernible. Sir John Herschel has referred to the "all but spiritual texture" of comets, and they have been elsewhere characterised as "visible nothings." The faintest cloud we see illuminated by the sun has far more opacity than is found in the brightest comet.

It has been suggested by the ingenious experiments of Tyndall that the tail is simply due to a chemical action of the light transmitted through the nucleus, which means that it is merely a spectral appearance and not a distension of the comet's materials. This would account for the generally observed fact that the tail flows in a direction away from the sun, though it would by no means eliminate other difficulties, such as the very sudden development of the tail in certain instances, and its remarkable variations as it is wheeled round the sun.

A repulsive force originated by the sun which has the effect of distributing the outlying materials of the nucleus into trains of different curvatures has been advocated as the true explanation of these phenomena; but this theory also has its objections.

The spectroscope usually reveals three bands, corresponding to the lines of carbon. In the case of Coggia's bright comet (Fig. 8) of 1874, Dr. Huggins wrote that three bands were seen in the coma and part of the tail. There was also a continuous spectrum, which in the comet's train became so decided as nearly to overpower the bright lines. D'Arrest, at Copenhagen, saw "a beautiful continuous spectrum, crossed by three bright lines of carbon." Dr. N. de Konkoly, at the Observatory of O-gyalla, Hungary, found the spectrum agreed perfectly with that of carburetted hydrogen. Mr. Lockyer inferred, from his observations that the blue rays were singularly deficient in the continuous spectrum of the nucleus of the comet, that it was of low temperature. Several foreign observers found the spectrum of the nucleus to agree with that coming from a glowing gas, the nature of which was indicated by the positions of the bright bands, which were found to correspond with the bands seen in the spectrum of olefiant gas or heavy carburetted hydrogen.

But notwithstanding the aid of the spectroscope, and the long period over which telescopic observations of comets have now extended, it must be allowed that the question is still much shrouded in mystery. No clear exposition of the phenomena presented by the trains can be gathered from known physical laws, the changes are so sudden, extensive, and curious, and differ so frequently in many details, as to defy explanation or prediction. But the forces of attraction and repulsion to which in a general way the appearances of comets are wholly attributable, are likely to affect different comets in different degrees, seeing that such bodies are often vastly dissimilar. Some of them approach the sun far within the orbit of Mercury, and will experience the extreme effects of these forces, while others, never coming within the orbits of the minor planets, will to a large extent evade their operation. Again, there are great differences in the density and size of these remarkable objects, which must render them liable in various degrees to the influences acting upon them. Additional observations are

still required regarding the visible character of comets, combined with the important facts of position and distance, both with respect to the sun and earth. When these shall have been duly compared, some of our present difficulties may disappear, and the physical constitution and extraordinary changes of these singular bodies will possibly admit of a more ready interpretation.

HOW HAILSTONES ARE FORGED IN THE CLOUDS.

BY ROBERT JAMES MANN, M.D., F.R.C.S., F.R.A.S., ETC.

IN a former communication* snow was spoken of as being to rain very much what hoar-frost is to dew. A less appreciative and at the same time less scientific view of the circumstances of the case would probably rather have suggested that hail was the frost-representative of the rain-drop. Hail is, however, in its most perfect form by no means simply frozen rain.

Under special conditions that sometimes present themselves, rain-drops are frozen into little balls of hard ice as they pass through very cold regions of the air in their fall towards the ground. In such instances the hail assumes the form of small round spherules of translucent or absolutely clear ice, of homogeneous texture throughout, and with smooth outer surfaces. All that is necessary for the production of hail of this character is that there should be rain deposited in a warm upper region of the atmosphere, and that this should have to fall through a very cold current of wind beneath. Hail, however, much more commonly presents itself as opaque white grains that look like miniature snowballs rather than frozen rain-drops. The form which is perhaps, on the whole, most commonly seen, and which is familiarly known as sleet, is of this nature. It consists of small white and opaque bodies, not more than $\frac{1}{10}$ of an inch across, and not unfrequently either soft or hollow within, and encased externally with a coating of hard ice. In all such circumstances the hail is primarily and essentially composed of snow-flakes which have been partially thawed, and then frozen again before the liquefaction has been complete. In such cases the snow-flakes are primarily deposited in a high and cold region of the air, and then pass during their subsequent fall, first through a warmer stratum of the atmosphere, and then through a very cold current nearer to the ground.

The most superficial consideration of the physical history of hail at once brings into prominent notice the remarkable fact that, notwithstanding its frozen condition, it is much less certainly and absolutely a production of winter than snow. It is capable of occasionally presenting itself in the season of winter; but as a general rule its grandest and most impressive manifestations of itself take place in warm seasons and climates rather than when and where the reign of winter has been established. It habitually waits until the earth is clothed with its garment of luxuriant vegetation, and it is quite a frequent visitant to the land of the olive and the vine. It is very common in regions that are of quite tropical heats. It is by no means a stranger on even the sun-scorched plains of India. Sir Joseph Hooker speaks of hail lying as thick beds of ice in sheltered nooks of the Sikkim Himalaya, and in the forest regions which intervene between the mountains of that district and the lower plains. Within the present century hail has been seen knee-deep in the streets of tropical Mexico. It is very common, indeed, in many parts of the sunny latitudes of Southern Europe. There can be few observant persons who are not aware that the most serious hailstorms, even in England, occur in the season of spring-tide and summer rather than in winter. It will be remembered that the hailstorm which in 1879 left its devastating track in the south-western precincts of London, and which did so much damage at Richmond and Kew, presented itself there in the approximately midsummer month of August.

Another notable circumstance which also stands prominently out in the physical history of hailstorms goes very far to account for the fact that they are so generally prevalent in warm seasons and places rather than in cold. In their most perfect development they are invariably associated with the occurrence of lightning and thunder. The heaviest and most destructive falls of hail are, indeed, incidental features in violent thunderstorms. It scarcely ever happens that a heavy fall of hail is not immediately preceded by lightning and thunder.

The ordinary forms of hail which are precipitated in connection with thunder-showers in England and

* "Science for All," Vol. III., p. 173.

in most other temperate countries fall upon the ground with a sharp rattle, which indicates the frozen solidity of the hailstones, but which is nevertheless quite innocent of all mischievous effects. The size of each hailstone is, in such circumstances, so diminutive that scarcely any mechanical result ensues even when it strikes upon brittle and frail bodies, although it may be moving with considerable velocity at the time. A hailstone that is a quarter of an inch in diameter scarcely weighs more than a couple of grains. But the case is far otherwise when the heavy artillery of the sky is brought into play. The hailstones then fall with a destructive violence that can hardly be conceived until it is seen. Leaves are stripped from the trees, and frail objects of all kinds are shattered into fragments; even sheets of corrugated iron which are exposed to the direct violence of the storm are riddled into holes. The hailstorm which occurred in the neighbourhood of Richmond on the night of the 2nd of August, in 1879, although its operation was limited to an area of fourteen square miles, inflicted a loss, in broken glass alone, which was estimated at £30,000. A hailstorm of a similar character which visited the eastern suburb of London on the 19th of May, in 1809, and which was described by Luke Howard, the well-known historian of the climate of London, broke 200,000 panes of glass. A hailstorm which burst over the northern part of London on the 30th of July, in 1826, is said to have been scarcely less destructive in its effects.

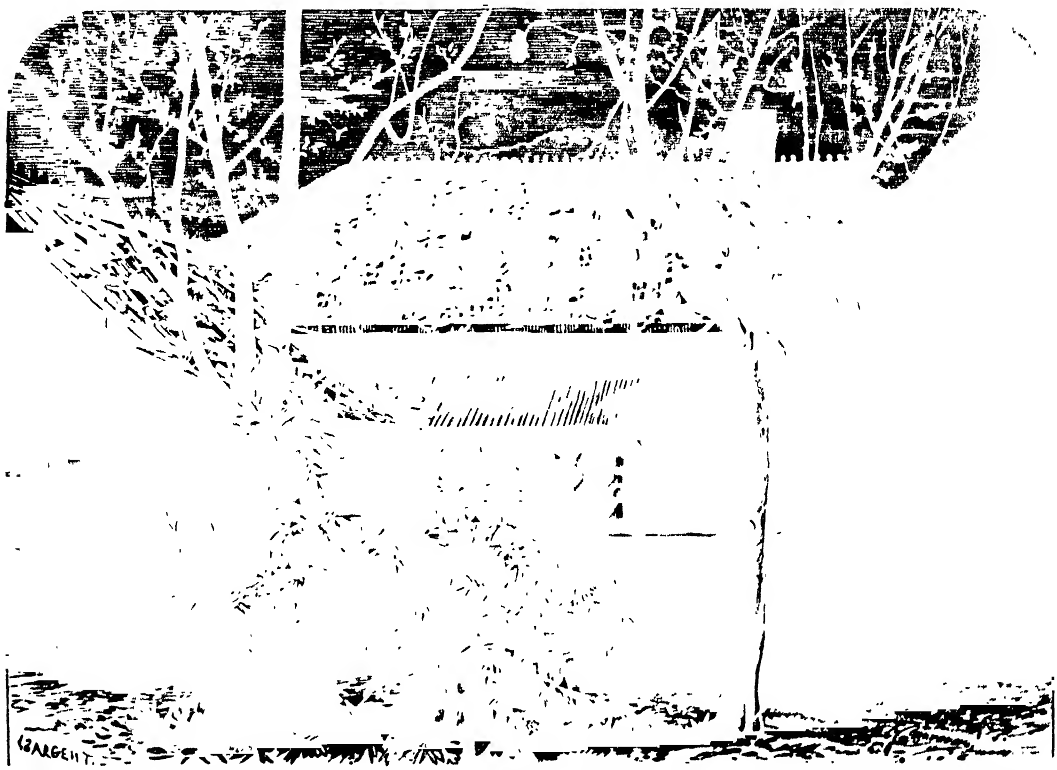


Fig. 1.—Appearance of a Small Dwelling-House in a Suburb of Pietermaritzburg, Natal, immediately after a Hailstorm, June, 1874. *(From an Original Photograph.)*

The Richmond hailstorm took place during the night which followed the 2nd of August, 1879. Distant lightning was observed playing incessantly about the horizon from nine o'clock in the evening, and a little before two o'clock in the early morning of August 3rd the storm burst over Richmond and the neighbourhood, in the midst of a violent squall of wind, accompanied by flashing lightning and rolling thunder. The chief fury of the storm was experienced between Ealing and Kingston. Hail fell during about ten minutes, and many of the hailstones were so large that they could not be put into drinking-glasses of an ordinary size. Individual specimens amongst them weighed a quarter

of a pound. One bolt-shaped piece of ice was picked up at Teddington which was nearly 4½ inches long. The greater part of the hailstones were, however, from 1¼ to 2 inches across, and were moulded into the form of flattened spheroids. All the glass which had a northern and north-eastern exposure in the track of this storm was broken.

The stones which fell upon this occasion were, nevertheless, of moderate dimensions in comparison with those which are sometimes met with in hotter climates. The preceding illustration (Fig. 1) very graphically represents the condition in which the roofs of dwelling-houses are sometimes left after they have been bombarded by stones of such calibre.

The engraving in this illustration was made from a photograph which was taken immediately after the storm. One hailstone which was picked up from the ground upon this occasion was found to weigh nearly three pounds. It is said that stones fell at Cazorta, in Spain, in 1829, which weighed nearly four pounds and a half. The German meteorologist, Kaemtz, describes a mass of hail that was reported to have fallen in Hungary in 1852 as measuring 39 inches in two directions, and as being 28 inches thick. In every case, however, where dimensions of this character are concerned, it is tolerably certain that the ice-mass described as having fallen from the sky as hail is the result of the sudden agglomeration and adhesion together of a more or less considerable number of separate hailstones under the influence of regelation—under the circumstance of the partial melting of the contiguous surfaces of ice when the separate hailstones are violently driven together, and of their immediately afterwards freezing together at the surfaces of contact when the pressure of the mechanical impact is relieved. The lumps of ice which are commonly found lying upon the ground after a heavy fall of hail are unquestionably of this character. Instances are well known in which panes of windows have been covered with a continuous coating of hail during the striking against them of a drifting hailstorm. It is quite conceivable that in some circumstances hailstones may even get frozen into a continuous mass when they are violently driven together during their passage through the air by the whirling of the wind. The storm-wind is ordinarily of such force during a discharge of hail that even the heaviest hailstones are carried along by it in an almost horizontal drift. The peculiar sound which is heard on the approach of a severe hailstorm, and which has been aptly likened to the noise made by the galloping of a large flock of sheep over hard rocky ground, has been referred by some meteorologists to the clashing together of the ice-masses in the air under the surging and irregular movements of the wind. As will presently be apparent, there is another explanation of at least one part of this sound which is also held to be probable. But whatever may be its source, the sound is, at any rate, one which is so peculiar that it can at once and at all times be recognised by practised ears as the warning note which is associated with the approach of hail.

There, nevertheless, are hailstones formed in the air as primary and quite independent accretions which are of very considerable size and weight, and which acquire their full dimensions without any fusion together of separate masses; and these primary hailstones of independent formation are at once to be distinguished by certain features of a very remarkable character. They invariably contain a central nucleus, or kernel, of partially melted and subsequently re-frozen and closely compacted snow. But this nucleus is either encased, or girdled round, by hard, transparent ice of a distinctly crystalline formation; and in some instances the ice-crystals are of very large size and of the most beautifully regular geometrical forms.

Fig. 2.

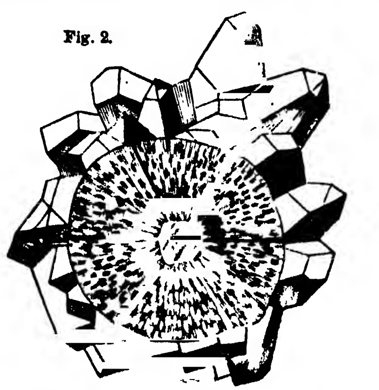
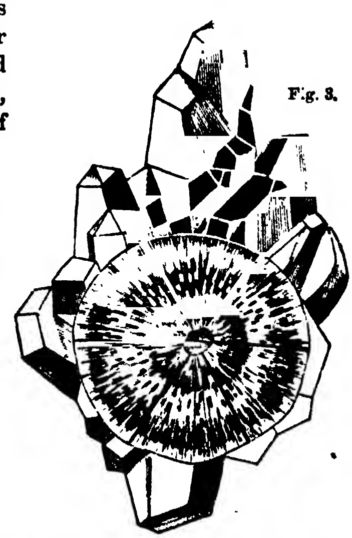


Fig. 3.



Figs. 2 and 3.—Crystalline Hailstones which fell on the 9th of June, 1869, near Tiflis, in Georgia. (*After H. Abich.*)

Small supplementary nuclei of soft white ice, and of a flattened form, are also not unfrequently found embedded in amongst the outside crystals. The two woodcuts that accompany this portion of the text (Figs. 2 and 3) are very excellent representations of hailstones of this character, drawn to their natural size. They are exact portraits of hailstones that fell during a violent storm in the Thrialeth Mountains, near Bjeloi Kliutach, a short distance south of the Caucasus,* on the 9th of June, 1869, and are, perhaps, the most interesting and instructive pictorial illustrations of crystalline hailstones that have ever been made. These figures are copied from drawings which were prepared at the time by Mr. H. Abich, a Russian gentleman of considerable scientific attainments residing on the spot, and which were afterwards engraved and published in a Russian scientific journal.

Some of the crystalline hailstones which fell on this memorable occasion were nearly three inches across, and weighed four ounces. The specimens from which these and some other analogous illustrations were drawn were immediately after the storm picked out of an iron vessel into which they had fallen. In all of these instances it was obvious that two quite distinct classes of operations, whether simultaneous or consecutive, had been concerned in the work of construction. In all there was a central frozen mass of tolerably pure white ice, rendered opaque and opalescent by the infiltration into its substance of minute air-bubbles. This mass was, however, most opaque in two parts, in the very middle of the central nucleus and in an outer investing shell; and between this opaque inner kernel and the outer shell there was more transparent ice, marked radially by six spoke-like lines of a glistening hue, and inclined to each other by quite regular angles of sixty degrees. The glistening rays lost themselves gradually in both the inner nucleus and outer shell, into which they passed by their opposite extremities. The entire central radiated mass was nipped in, or compressed, at the sides, and it was surrounded along the circle of largest diameter by a zone, or wreath, of large crystals of bright transparent ice, which were, for the most part, of exquisitely regular geometrical symmetry. Some of these large crystals were quite distinct and isolated from the rest, whilst others were connected by their sides, and, as it were, partially fused together. The greater part of them were moulded into the form of six-sided columns, with obtuse rhomboidal prisms capping their ends. But there mingled amongst these other broader varieties of more or less flattened and tabular shape, and often rounded away by incipient fusion at the edge. As a rule, the outward or longitudinal growth of the crystal appeared to have occurred in a plane corresponding more or less nearly with the rim of the wheel-like, flattened mass. But occasionally well-developed crystals appeared also on the flattened sides of the spheroidal mass and, when detached from it, left pits on its surface which corresponded with the completion of the pyramidal forms of crystallisation in that direction. These large hailstones melted away so slowly that on the morning following the storm there still remained in the iron vessel in which they had been caught a considerable number of them, changed into the condition of clear lenses of ice.

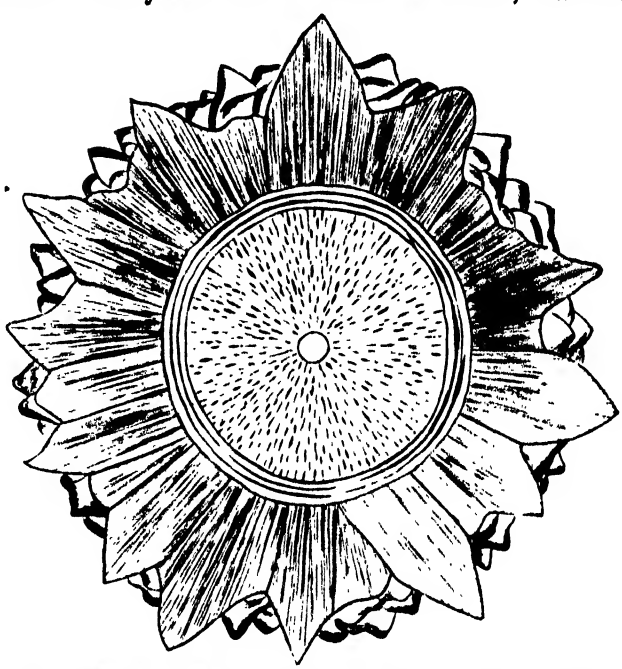


Fig. 4.—Diagram representing a Section of a Crystalline Hailstone that fell in one of the Western Provinces of France on the 4th of July, 1819. (*After Captain Delcros.*)

The shapes sketched by Abich derive an additional interest from the circumstance that they closely correspond with an account of the intrinsic mechanism of crystalline hail which was given by Captain Delcros, a French officer of engineers, in 1819,

* Not far from Tiflis, in Georgia.

and which was published about that time in a scientific journal* by M. Arago. A hailstorm at that period ravaged a large portion of the western districts of France. The hailstones shattered the roofs as well as the windows of the houses, knocked off the branches of the trees, devastated the cultivated fields, and wounded and killed living animals feeding upon the pastures. Captain Delcros had sections cut of some of the most remarkable and characteristic of the stones that fell, and he found that they consisted of masses of compact white and opaque ice enclosed within cases of clear crystals. Fig. 4 is a copy of one of the drawings in section which Captain Delcros made. It represents a small central nucleus of opaque ice surrounded by a thick coating of bluish ice marked by radial lines running from the centre to the outer circumference, and yet again surrounded by a coating of concentric layers. This external coat was in its turn encased in a congeries of large crystalline pyramids of clear ice, connected together by a packing of smaller crystals inserted between. The clear crystals, however, constituted a complete case, instead of being limited to a circumferential wreath, as they were in the specimens described by Mr. Abich.

Hailstones are not unfrequently met with in which successive concentric layers of clear bluish and of opaque white ice occur alternating with each other, as represented in Fig. 5.

These coats, which are arranged over each other like the coats of an onion, have been sometimes familiarly spoken of by observers as consisting of alternate layers of ice and snow. The German meteorologist Kaemtz, in alluding to large hailstones, says that they are composed of alternate layers of snow and ice, and that they are covered externally by a thick coat of ice. He also states that completely formed hailstones invariably have a snowy nucleus. Large hailstones occasionally assume a distinct pear-like form, with a protuberance at one side, as if they had enlarged most rapidly in the direction of their fall. Descartes and some other observers held that this somewhat irregular pear-like shape was in reality due to the hailstones being the fragments of shattered spheres of larger dimensions. This, however, has never been satisfactorily proved, and the meteorologists of the present day more incline to the opinion that the pear-like shape is the natural and original form in which the hailstone is cast.

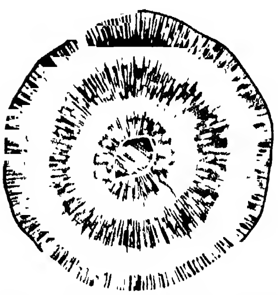


Fig. 5.—A Hailstone with Concentric Layers of Clear Blue and Opaque White Ice. (*After Abich.*)

It will now, after this preliminary description of the composite structure of crystalline hailstones, be easy to understand what the chief difficulty is that scientific men have had to contend with in their attempt to explain the way in which these chilled shot of the sky are formed. Crystals of large size, in most other circumstances, are conceived to require considerable intervals of time for their construction. They are so slowly and deliberately built up by the methodical and orderly aggregation of their molecules upon geometrical lines, that the finest crystals are almost universally found to be those which have occupied most time in their growth. But how can there possibly be any deliberate and slow aggregation of the component molecules in the case of hail? A mass of ice weighing three or four ounces cannot be poised in the air like a snow-flake whilst its prisms and pyramids are being deliberately fashioned by the slow and delicate process of molecular attraction and adjustment. The hailstone which is precipitated with the force of a projectile from the air must be the creation of an instant, notwithstanding the cunning regularity and methodical order of its lines. There is, no doubt, very much that has yet to be ascertained in regard to the process by which these beautiful ice-crystals are fabricated in the sky; but the direction in which the solution of these unknown agencies has to be sought is indicated in no doubtful way by one of the characteristics of the hailstorm, which has already been incidentally alluded to—the circumstance, namely, that it is so invariably associated with lightning and thunder. This association, indeed, has been a matter of the most familiar experience from very early days. The first great hailstorm of which there is any authentic record had "fire mingled with the hail," and "fire ran along the ground" as the hail fell to the earth. In the La Braconière storm, described by Captain Delcros, incessant lightnings flashed over a tract twenty geographical miles wide, and extending from the Tyrol to Lower Saxony. In the Georgian storm the precipitation of hail was preceded by lightning and thunder, and the lightnings flashed unceasingly from the clouds as it drifted away. In the Richmond storm

* Poggendorff's "Annalen," 1819.

lightning and thunder commenced eighty minutes before midnight; the hail began to fall seventy-five minutes after midnight, and the lightning was then still seen for another half-hour.

In order to apprehend the full force of this connection, it must be carefully kept in mind that one of the essential effects of a powerful electrical discharge through the atmosphere is the violent expansion of the tract of air that lies in its path. Thunder is incidentally a consequence of this result. Air does not remain rent, as solid bodies do, after it has been torn asunder by a disruptive operation of this character. The air which has been driven away by the expansion along the track of the discharge is immediately forced back by the elastic resistance which it meets, and by the superincumbent pressure of the surrounding mobile mass, and the air-particles, in consequence, strike together by a sudden impulsive clash. This is the source of the sonorous vibration which rumbles on into the roll of the thunder. But whenever air is suddenly and violently expanded in this way it is chilled by the expansion. A large amount of sensible heat becomes latent and insensible with the production of a corresponding amount of cold. In the case of the passage of a discharge of lightning, the expansion is both very sudden and very large, and the cold is, in the same degree, intense. Such, in all probability, is the source of the cold which, in the formation of hail, converts aqueous vapour into aggregations of ice.

Some curious and ingenious experiments of M. Dufour, of Lausanne, which were described in the "Bibliothèque Universelle" for 1861, seem to tend to confirm the idea that crystalline ice can be produced by electrical discharges in this way. M. Dufour caused small spherical drops of water to float in a mixture of almond oil and chloroform, and found that he could then reduce them to very low temperatures without freezing them. But when, in such circumstances, he passed a smart shock of electricity through them, they were instantaneously turned into small spherical masses of solid ice, which had white snow-like nuclei within, and hard transparent ice-crystals surrounding and enclosing the central mass and radiating out from it, exactly as occurs in the crystal-studded hailstones. A careful observer, M. Bois-Geraud, states that he has frequently seen large drops of liquid rain fall upon ground possessing a temperature considerably higher than 32° Fahr., and converted into solid ice at the instant of contact by the mere influence of the mechanical shock. It is, perhaps, not unworthy of note that the distinguished electrician, M. de la Rive, regarded the whizzing noise which accompanies the fall of hail as being mainly a brush-discharge of electricity; and, in support of this opinion, he cited the fact that thunder generally ceases to be heard so long as the actual deposit of the hailstones continues—a circumstance which is well authenticated, but which some other observers have been inclined to attribute to the roar of the hail being loud enough to smother the sound of the thunder.

The production of hail, however, requires a copious supply of free moisture as well as the instantaneous production of intense cold. This condition is very obviously and satisfactorily explained by the fierce conflict of wind which is the never-failing accompaniment of hail. The hailstones are whirled to the earth in the midst of a violent squall, which seems to burst in quick succession from all points of the compass. Hot and cold currents of wind are suddenly driven together, and from the mingling of these currents aqueous vapour is deposited. Sir John Herschel long ago pointed out that an extremely cold current of air must be suddenly projected into the midst of warm air thoroughly saturated with moisture to form hail. The water of the ice-cataract is supplied by the winds, and its cold is furnished by the lightning.

It is almost universally noticed that hailstorms restrict their ravages to comparatively narrow belts of land. In England the devastated area is rarely more than a mile or two miles long, and a few hundred yards broad. The Richmond storm, which was of exceptionally large extent, was seven miles long and two miles broad. Much larger tracts are, however, sometimes laid under contribution in other parts of the world. A hailstorm which passed over France in 1788, and which caused damage that was estimated as amounting to £987,600, left the mark of its track from the Western Pyrenees to the Baltic Sea, an extent of quite six hundred miles. It moved over this range in two parallel bands eight miles asunder, and with a breadth of four miles for one of the bands and of eight miles for the other, and it travelled at the rate of forty miles an hour. Heavy rain, without hail, fell in the interval that lay between the parallel bands. A fringe of heavy rain almost always attends upon the precipitation of hail. The actual fall of hail is rarely prolonged at one place for more than eight or ten minutes. It will at once be perceived that the belt-like deposit of the

hail is a natural consequence of its being due to the mingling of oppositely moving currents of wind. The hail falls where such antagonistic currents overlap at their edges.

Mr. Abich's account of what he observed in the great storm near Tiflis comprises all the main features which characterise the production of these destructive disturbances of the atmosphere, and is, on that account, worthy of being again referred to with some fulness of detail. The three previous days in the neighbourhood were warm and still, with a very gentle south-west wind and a steady barometer. About five o'clock on the evening of the 9th of June a dense obscuration of the sky towards the north and east gave indication of an approaching thunderstorm. This developed itself so rapidly that there was scarcely opportunity, after it had appeared, to find shelter beneath a shed before the storm burst with excessive fury. The storm-wind swept up with "tearing speed," and the gusts came intermittingly from the north-east and from the east-south-east. The flashing of the lightning and the rolling of the thunder were almost unceasing, and then in a moment, with a roaring rattling noise, a cataract of hailstones of the size of hens' eggs was discharged, almost with the impetuosity of an explosion. These fell in all directions and with the utmost diversity of slant, sometimes being drifted along in a nearly horizontal course. It was immediately noticed that the stones were of irregular outline and sharp-cornered, although often broken and shattered by the fall. A closer examination of them showed that the irregularity and sharpness were due to the piling together on the outside of the large and symmetrically-formed crystals of transparent ice which have been already alluded to. The precipitation of these large crystalline bodies continued for about twelve minutes, and the storm then swept away amidst the prolonged rolling of retreating thunder and with a deluge of rain. Panes of glass in dwelling-houses were in many instances drilled with even round holes, which thus indicated the great momentum of the frozen projectiles.

It has been remarked that the sky very commonly assumes a distinctively characteristic appearance before the precipitation of hail. The blue colour is not of its usual deep tint, and fine threads of cirrus cloud are deposited in the higher regions of the atmosphere. The air near the ground becomes oppressively warm, and the high temperature diminishes very rapidly upwards, the thermometer often indicating a lower reading than 32° Fahr. at an elevation of 5,000 feet, notwithstanding a quite insupportable heat below. A powerful upcast of the heated air then sets in, carrying with it copious loads of redundant moisture, which is very soon piled up, as it is condensed into heavy cumulus clouds. The ascending moisture-laden air at last becomes suddenly and intensely chilled, and simultaneously with this the discharge of lightning begins. The higher region of the cirrus clouds is charged with the usual positive form of electrical fire which is the constant and natural production of the vapours that rise from the positively electrified surface of the sea. But the storm clouds which are generated in the heated upcast from the land, as was first shown by the distinguished electrician, M. Peltier, are as constantly saturated with *negative* electric force. This electrical antagonism of the higher and lower layers of the clouds, no doubt, has much to do with the flashings of lightning and the whirlwind commotions which ensue. In the South African colony of Natal the storm cloud may often be seen to arise as a small wisp of vapour in the clear sky hanging over the seaward slopes of the Drakenberg Mountains, which then begins to revolve and enlarge until it is matured into a thunderstorm. The discharges of lightning after this occur, and the thunderstorm sweeps down from the mountains into the lower plains. It is well known that hail is sometimes formed in very high regions. M. de Saussure observed hail eleven times during his sojourn of thirteen days on the Col du Géant, at an elevation of 11,000 feet. The Chamounix guide Balmat experienced a hailstorm on the summit of Mont Blanc, on the memorable occasion when he passed a night there; and it is said that hail is continually found beneath the snow on the top of that monarch of the European mountains.

It was at one time a dogma of meteorology that hail does not fall during the night. This is, however, certainly a mistake. It will be remembered that the severe hailstorm at Richmond made a notable protest against this assumption, as it occurred in the small hours immediately following midnight. It is nevertheless true that heavy hailstorms do most commonly take place shortly after noon and during the period of the greatest heat of the day. The exact time, however, which seems to be most favourable for the formation of hail varies very much in different places. It is influenced to a considerable extent by the physical circumstances which are concerned in setting up strong air-currents. The near proximity of high

mountains and deep valleys certainly tends to the frequent production of hail. M. Despine, an Italian meteorologist, who carefully investigated the situations which were most liable to hail in Sardinia in 1840, came to the conclusion that the direction of high mountain-chains obviously exerted a strong influence. All the situations which were most frequently visited by hail held a somewhat similar relation to the high mountains. This, of course, may be looked upon as a natural consequence of the power which mountains possess to inaugurate violent conflicts of oppositely moving winds.

The discovery of the intimate physical relation that exists between the precipitation of hail and electrical disturbance very soon and very naturally suggested the idea that it might perhaps be possible to prevent hail by relieving the electrical tension of the clouds through the instrumentality of lightning conductors. Twenty-five years ago M. Arago inclined to regard this notion with some favour, and suggested that the service might, perhaps, be most efficiently performed by sending captive balloons up into the storm-clouds. Various experiments were actually tried in some of the vine districts of France, and a name was invented for the apparatus that was thus brought into use to tap the aërial reservoirs of the lightning. It was called "paragrêle,"† to indicate its close kinship with the "paratonnerre," or lightning conductor. There is an obvious reason, however, why no anticipation of success from any expedient of this kind can be reasonably entertained. Hailstorms produce their destructive effects not where the electric disturbance originates, but long after they have been launched upon their impetuous and quite irresistible career. What paragrêle could reasonably be expected to produce any appreciable effect upon a whirlwind sweeping along at the rate of forty miles an hour, and dropping its ice-bolts in its path? Hence the paragrêle is no longer regarded with either confidence or hope by meteorological science, although it still has some advocates amongst sanguine enthusiasts.

† Paragrêle: from *parer*, to ward off, and *grêle*, hail. The apparatus is described and figured in "Science for All," Vol. I., p. 269.

THE STARFISH AND ITS RELATIVES.

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A STARFISH (Fig. 1) is one of the most "common objects of the sea-shore;" a specimen is easily found, and, once found and examined, it will be seen to be, of all the creatures commonly known to us, one of the most remarkable. Unlike a crayfish or a frog, it has not its mouth placed near one end of the body, but in the centre of its lower surface. We cannot speak of its right side and its left, but only of the rays or "arms" into which its central disc seems to be drawn out; while there are, again, no organs developed in it which we can compare in structure either to fins, or to our own arms and legs.

When we look around among its immediate zoological relations we see clearly enough that the very same points are to be made out in them. If, for example, we take a brittle-star (*Ophiurid*) we find five arms and a central disc. With the sea-eggs, or echini,* a little more care is needed, for in them there are no five outspreading rays, and the spines on the outer surface of the body are longer, and all the plates of the test or "shell" are firmer; yet we find five different sets of suckers, arranged in rows, which it is easy to compare with the suckers in the arms of the starfish itself. The further we get from this last, the more do its more especial characters seem to disappear; witness the sausage-shaped sea-cucumber on the one hand, and the beautiful stalked sea-lily (*Pentacrinus*) ‡ on the other.

Notwithstanding all this diversity, these several forms may, by the leading points of their anatomical structure, be shown to be more closely allied to one another than to any other form now known to us. Let us take, step by step, the characters of the starfish, and so see what these anatomical points are.

If we take for examination the common form of our own coasts (Fig. 1), we find that we have to do with a flattened creature of a somewhat

* These creatures are often called sea-urchins; but "urchin" is only a modified form of the French for hedgehog (oursin).

‡ *Fig.* 1, p. 163; Fig. 3, p. 165; Fig. 5, p. 167.

orange-yellow colour, in whose skin a number of calcareous bodies are to be felt by the fingers, and attached to some of which there is a number

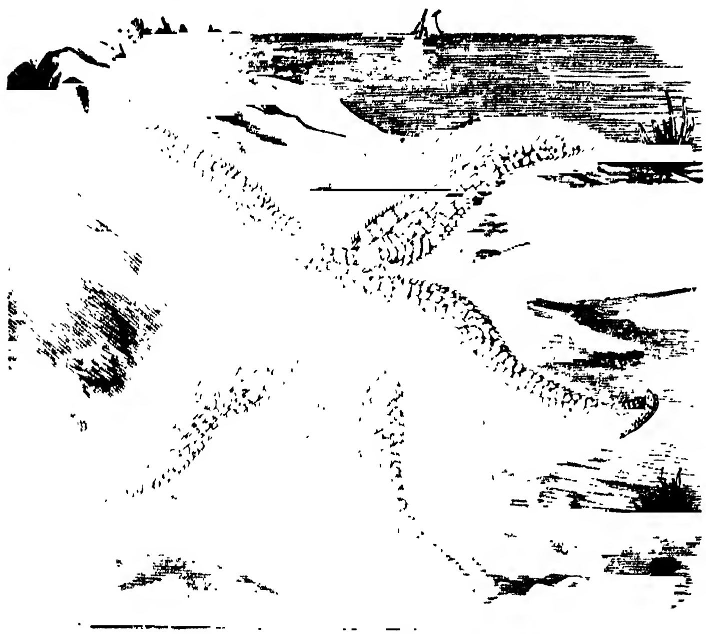


Fig. 1.—The Common "Five-fingered" Starfish.

of short spines, many of which are arranged in very regular rows. When we look at the under surface, which is very much whiter than the upper, we see that from the central mouth there spread out five grooves, in which there are placed a very large number of suckers, and these suckers are, with a little care, seen to be set in what appear to be cross rows of four. The arm gradually diminishes in width on its way to the tip, where it is a little bent up, and provided with a special organ, which we shall soon find out to be an eye. The suckers are simple soft tubes, which pass out between the solid joints which go to make up the principal portion of the skeleton of the arm, and are the chief means of progression. The apparatus by which this is effected is very curious and somewhat complicated, but it is to be regarded as a very complete piece of work, as the following account will show.

The whole canal system, the "pipes" of which are known as the "water vessels," is connected together by a ring round the mouth, and this ring has its more special communication with the outer world by means of the so-called "stone canal." The tubes which pass out from the circular vessel run down the groove of the arms and communicate with the sucker-feet and with a small swelling (Fig. 2, *a*), which is set at the base of each sucker; these swellings are capable of contraction, and they, by driving out the water that has passed into them from the common connecting-tube, are enabled to fill the suckers and so to bring them into a more firm condition. Just as each foot has its own special swelling (which is known technically as an *ampulla*), so, too, there are special swellings in the central portion of the water-system. These are set between each radiating canal, and are named *Polian vesicles*, in honour of the Italian naturalist, Poli; like the more special ampullæ, they are provided with muscles in their walls, and their contraction, aided by the delicate processes which line the walls of the canal tubes, is sufficient to drive the sea-water along the canals and so into the feet.

Whence comes this sea-water? The answer should rise to the lips of every reader who has noted the statement already made as to the communication of the water-vessel system with the outer world by means of the stone

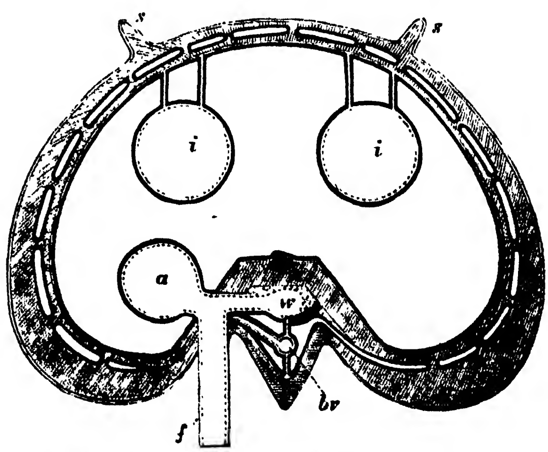


Fig. 2.—Diagram of the Water-vessel System of the Starfish.
(*After Ludwig.*)
a, Ampulla; *f*, Sucker; *w*, Water-canal; *br*, Blood-vessel; *i*, Intestine; *s*, Spine.

canal. A careful inspection of Fig. 3 might lead to the same answer, for it is shown in that figure that there is at the upper pole of the body an ellipse-shaped plate, which is dotted over with minute pores

(*m*). This "modified" plate is the stone canal, and as it lies on the outer (and upper) surface of the body, its pores are freely open for the entrance of the sea-water. We shall explain later on the history of this curious arrangement, and will now only say that there are deposited in its walls, just as there are deposited in several portions of the starfish's body, a number of small, hard bodies, which are, like the skeleton and spines of which we have already spoken, principally made up of carbonate of lime.

The sucker-feet and their connecting canals are not, however, all that is to be found in the groove of the arm (Fig. 4). If we carefully separate the suckers on one side from those of the other, we shall find that there is a delicate band running over the water-canal, and we shall, on dissection, find that this band may be traced into a circular ring of whitish substance, which, like the canal-system, runs round the whole of the disc, and connects with one another the double series of cords (for double they really are) which belong to each arm. This is the *nervous system* of the starfish, and there are lessons to be learnt from it which have a very wide and general bearing. On a previous occasion* we quoted a saying, "Touch is the mother of all the senses." Now the real meaning of this aphorism lies in the following facts. At a very early period in its history nearly every animal consists of two layers; from the outer one, which is technically known as the "epiblast," swellings are developed, which gradually take a deeper position in the body, and go to form the chief part of the nervous system. Without a knowledge of the history of the chick, for example, it would hardly ever be imagined that the greater part of the "spinal cord" of the fowl had arisen from the same layer of cells as that which had given rise to the outer skin. Such, however, is the fact, and the importance of a knowledge of the arrangements of the nervous system in the starfish is due to the close connection which still obtains in this form between the investing skin and the underlying nervous cords. In other animals similar relations are to be found, and while we cannot and must not deny that it is to the study of development that we owe our knowledge of the origin of the nervous system, we may very properly draw attention to the support which is afforded to its teachings by the observations of comparative anatomists. And here, again, we have another example of the truth on which the great philosopher and naturalist insisted when, in words that have been thus translated, he taught us that—

> "All forms have a resemblance, none is the same as another;
> And their chorus complete points to a mystical law."†

While applying this teaching to practice, we may say that he who would fully understand the structure and relations of animals must always look upon the study of developing and of developed forms as the two sides from which it is necessary to carefully examine every living creature.

We have not yet, however, done with all the organs of the body which make their way into the arms. (Fig. 4.) The digestive tract sends up a long, dark, much-sacked tube on either side, and at the base we find a duct which leads from glands of not so great a length in which we find the sperm, or the eggs, developed. Before passing to the digestive system, let us say just a word as to that special organ at the tip of the arm which we have already asserted to be an eye. This tip is generally bent up, thanks to a muscle which runs along the back of the arm under the skin, and it is thus more completely exposed to the light; it is provided with about a hundred spots, more or less distinctly coloured red by pigment, and surrounded by cells which are rod-shaped, and enclose among them a transparent body. The whole arrangement is placed on a swelling of the nerve cord, and nerve fibres have been observed to pass to it.‡

There are no special hard structures in the way of teeth in the starfish itself, and the opening of the mouth is pretty wide. The end of the intestine opens on the other side of the disc, not far from the centre of it, by a small and inconspicuous orifice. The tract is very simple, and the only point of importance which we need note with regard to it is the out-pushing of its parts into the several arms.

Coming now to the hard parts which make up the skeleton, we have to commence by drawing attention to one or two important considerations. It is obvious

* "Science for All," Vol. II., p. 309.

† "Alle Gestalten sind ähnlich, und Keine gleichet der andern,
Und so deutet der Chor auf ein geheimes Gesetz."—*Goethe.*

‡ The genial and accomplished Edward Forbes gives an account of his adventures with a peculiarly fragile starfish (*Luidia*, so named in honour of Edward Lhywd), which we cannot refrain from quoting:—"Whether the cold air was too much for him, or the sight of the bucket too terrific, I know not; but, in a moment, he proceeded to dissolve his corporation, and at every mesh of the dredge his fragments were seen escaping. In despair, I grasped at the largest, and brought up the extremity of an arm with its terminating eye, the spinous eyelid of which opened and closed with something exceedingly like a wink of derision."—Forbes, "British Starfishes," p. 139.

that that part of the body which is connected with the suckers may be sharply marked off from the parts that have no direct relation with these tubes. This matter is not very easily made out in the star-fish, but is exceedingly well marked in its close

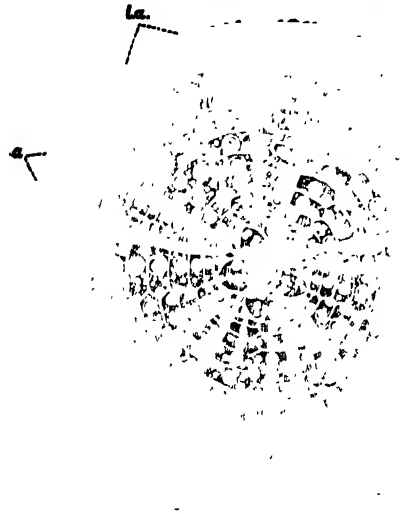


Fig. 3.—Test of Echinus.
Interambulacral or Unperforated a.

zoological relation, the sea-urchin; and we will, therefore, anticipate matters a little by describing the shell, or, more properly speaking, the *test*, of this animal (Fig. 3). Examining this carefully, and taking no note for the moment of the plates at the pole opposite to the mouth, but looking only at the series of plates which are in relation with the general surface of the body and go to form its "corona," we see that it is divisible into five similar regions, that each of these regions consists of four rows of plates, and that of these rows one pair is perforated by a number of small pores, while the plates of the other row are larger (though that is a matter of no importance) and are not perforated at all. The former series or rows of perforated plates are known to zoologists as the "ambulacral plates," while the others are, from their position, known as "interambulacral plates"—that is, plates which are unperforated, and between the rows of those pierced by the suckers. So much is clear and easy; and we can now see, by an examination of Fig. 3, that on either side of the groove in which the suckers are placed there is a single plate which carries no spines, and that on either side of this there are several plates which do carry spines. When we look more closely, we find that those plates which do not bear spines have very much the same relation to the suckers as have the ambulacral plates of the sea-urchin, and that they only differ from them in the fact that the suckers pass out between them instead of passing through them. Similarly, the spine-bearing plates are those of the unperforated series; and we have, therefore, in making any exact examination of the skeleton of the star-fish, to distinguish between the *perforated* and the *unperforated* plates. The spines on these plates are never very long in the starfish, and it is needless for us to say very much as to their structure. The most remarkable point about them is the fact that some of them, instead of growing into more or less solid rods of carbonate of lime, become divided at their extremity, and thus form the two or three snapping processes which are hinged on to the end of the modified spine, and are to be seen in active movement in a living starfish, twisting about, and, by the aid of muscles, seizing upon whatever is minute enough to come in their way. These bodies were long ago observed, and were for a considerable time thought to be independent animals living as parasites upon the surface of the creature; and it was for this reason that they had applied to them the not very elegant term of *pedicellaria*. This name they still retain. Small and comparatively inconspicuous as the spines are in the starfish, they are often of great size in the sea-urchins, and form, it may be, club-like or cigar-like spines, sometimes elegantly banded, or, as in the "Piper," they may be more delicate though still strong, and may well be compared to stilts, in length very much surpassing the longest diameter of the body.

Of the systems of organs, it now only remains

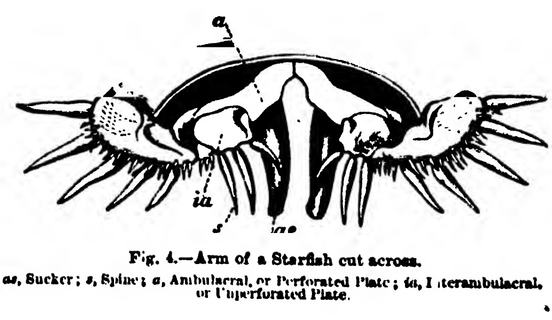


Fig. 4.—Arm of a Starfish cut across.
su, Sucker; *s*, Spine; *a*, Ambulacral, or Perforated Plate; *ia*, Interambulacral, or Unperforated Plate.

to speak of the arrangements by which food is carried to different parts of the body—the blood-vessel system, and of those by which the process of breathing is effected. With regard to these, we have not, however, much to say. As to the former, we do not know so much as it is to be hoped we

soon knew from the activity and opportunities of anatomical investigators. As to the latter, the arrangements are most delightfully simple. We can easily imagine that when a creature is very small, and has a very thin body wall, the fresh oxygen which it requires may be gained for it by mere exchange through this body wall, and, when we find such a process, we say of the creature that "its respiration is vague." Well, the starfish has adopted a method of respiration which is hardly anything of an advance upon this. Owing to the fact that it has not a continuous skeletal covering, as has the sea-urchin, there are left in its body wall a number of thinner spaces interspersed in the calcareous network, and through these the creature protrudes a portion of the lining wall of its body cavity, which is thin and membranous. In the body cavity there is a quantity of fluid which is driven about by the delicate processes, or cilia, developed in its lining wall, and the fluid is thus brought into very close relation with the sea-water in which the starfish lives. It is probable, too, that the fresh sea-water which comes in by the stone-canal is in some way able to pass into the body cavity, and so to mix with the nourishing fluid there contained. From this fresh sea-water, whether thus introduced or that surrounding the animal, the nutrient fluid gets what is a most important part of the nourishment of every living organism—a fresh supply of oxygen.

Of the blood-vessel system, we may say at once that there is considerable difficulty in finding a true heart or contracting organ which will drive the blood through the body. As to the rest, a blood vessel appears to run along each arm (Fig. 2, *bv*), in company with the nerve-cord, whose course we have already described. Just as the nerve cords and the canals or "pipes" of the water-vessel system are connected with each other by a circular piece which runs around the disc, so, too, is there a circular blood-vessel running round the mouth. There are other vessels also, which we need not describe; but we shall, before we have done, see what is the possible meaning of this circular blood-vessel surrounding the starfish's mouth.

We have now made out the leading characters of the anatomy of a starfish, and we have seen enough, at any rate, to show us that in some important points this creature and its allies differ very markedly from all other forms. Henceforward we shall be disposed, first of all, to agree with those zoologists—and in this point the zoologists are nearly agreed among themselves—who separate off the group to which the object of our study belongs from all other animals. To this group there has been applied the name of Echinodermata, from the characters of their integument (*echinos*, a spine; *derma*, skin).

The illustrious Cuvier was struck by the fact that the group did not exhibit an equal development of right and left sides—that, in fine, the Echinodermata were not *two-sidedly* symmetrical. He saw that in their adult condition—and the earlier or larval stages were not known to him—the parts of the body were equally disposed along rays or radiating lines—that, in fact, they were *radially* symmetrical; and he proposed therefore to associate them, under the great head of the *Radiata*, with such animals as the sea-anemone and the coral-making animals, which, with the sea-jellies, also exhibit a rayed symmetry. For a long time this division of the animal kingdom was regarded by naturalists as a natural and just one, and it was not till the year 1848 that it was successfully attacked; earlier than this, indeed, a small portion of the group had been cut off from it, and associated with another great division; but it was not till the two German naturalists Frey and Leuckart demonstrated that the sea-jellies, corals, and so on, differed from the rest of the Radiata by the characters of their digestive tract, that the death-blow was really given to this classification. At the same time, these naturalists insisted on the fact that the Echinodermata had their closest alliance with some of the worms, in which, as we may note, two-sided symmetry is very evident.

We have, then, two views as to the relationships of the starfishes: one, still held by some American naturalists, is that the starfishes are really allies of the sea jellies, sea-anemones, corals, &c.; the other, which is held by the majority of naturalists, is that their closest affinities are with the worms. As we shall shortly see, there are two lines of argument by which this may be supported: the one is the striking resemblance that there is between some worms and some of the sausage-shaped sea-cucumbers; and the other is the remarkable course of development through which the young starfish passes. In a larval stage it swims about freely, and exhibits a completely marked two-sided symmetry.

That we may, however, have the whole case before us, it remains still to mention a third view as to the history and origin of these interesting and difficult forms. It has been put

forward by the eminent naturalist who is now keeping in high honour among anatomists the name of the little German town of Jena. Professor Haeckel holds that the starfish is really a colony of several worm-like creatures, which have joined themselves together by a common mouth and disc. This view of the "colonial" character of the echinoderm is, with his accustomed vigour, stated by the German naturalist to be the sole theory which attempts "the genetic explanation of this remarkable group of animals." It is impossible to deny that there is much in the structure of the arm of a common starfish which supports the view of Professor Haeckel, and we have ourselves been already able to see how the different organs of the animal all find their representatives in each one of the arms. There are, of course, a number of difficulties which still stand in the way, and we are rather directing attention to it for the purpose of illustrating how even in the details, dry as they must often seem, of the facts of anatomical structure, it is possible to educe, by the aid of a skilfully cultivated imagination, explanations which, even if they do not explain all that seems to need explaining, do yet throw on the facts themselves a bright and instructive light. By some conservative zoologists such views are held to be wild in the extreme, and the "laudator temporis acti" laments the cruel fate that causes him to live in a time of speculation. Even here, however, we find true the words of the wise man of old, that there is no new thing under the sun; and it may be of interest to recall to the memory of the objectors that, so long ago as the year 1837 the French naturalist Duvernoy spoke of the starfishes as "serpents with many bodies, but one mouth."

It is now necessary to sketch briefly those series of changes during which the two-sidedly symmetrical larva is converted into the five-rayed starfish; for this purpose, however, it is necessary that we should commence with an account of a somewhat simpler history than that which must be given of the type we have chosen. Let us begin, therefore, with one of the sea-cucumbers, or holothurians—those curious sausage-shaped creatures which it is not always easy to distinguish from some worms. When the egg of these creatures has passed through a series of changes which are, on the whole, common to it and all other eggs, it appears as a somewhat elongated or oval body, which is at first richly provided with those delicate processes which are ordinarily known as *cilia* or lashes. These cilia become confined to a special band, and the larva is seen to be provided with a "digestive tract." On the front region of the upper part of the body a tube is formed by the special growth of cells in that region; this tube grows downwards and inwards until it comes in contact with the digestive tract just mentioned. Coming near it though it does, it does not open into it, but curves round it, and then divides into three portions. Of these three parts, two have quite a different history from the third; they separate from it and from one another, and come to lie on either side of the digestive cavity. As they grow they become connected with it and with the body wall, and during their growth there is gradually formed in the middle of each mass of cells a cavity; it is this cavity which forms the space which we learn to regard in the adult starfish as the *body cavity*. The inner end of the third tube, or that which is nearest the digestive tract, grows out into five swellings, and these five swellings each form one of the five divisions of the water-vessel system. The tube by which these enlargements are connected with the body wall still remains, and it is now pretty easy to see that it is this tube which forms the stone-canal in the starfish. To put things on an exact footing, we may add that in the "sea-cucumber" (Fig. 5), whose history we have been describing, the stone-canal becomes in time separated from the body wall, and hangs freely in the somewhat pretty spacious body cavity. In the starfish, however, and in the sea-urchin, the connection persists throughout life. As these tubes grow out, and the body cavity and its lining walls become definitely fashioned, the sea-cucumber takes on the definite form of the adult, and no part of the larva is cast away.

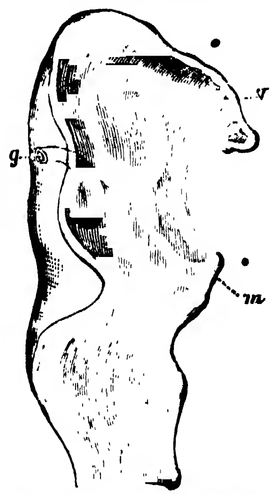


Fig. 5.—"Sea-Cucumber" Developing.
m, Mouth; i, Stomach; v, Vent; g, Orifice of In-growing Tube.

In the ordinary history of the starfish, a large part of the body of the larva never comes to take any share at all in the formation of the organs of the adult, and, as this complicates matters a little, we have preferred to start with an easier case. We have, however, learnt, or at

least read, so much about the starfish itself, that it is necessary for us to give a little attention to its earlier stages. Here we do not find any thickening of the outer body wall growing down as a tube, but instead of that there is given off on either side of the stomach an enlargement, which gradually grows out and goes chiefly to form the two walls of the body cavity. One of the outgrowths becomes also connected with the outer surface of the body, and the connecting tube is, as we might suppose, the future stone-canal. The processes grow and grow, and finally surround part of the intestines. It is not, however, the more anterior portion that they surround, and so it happens that the anterior part becomes cut off and gradually lost, while a new mouth is developed between these two processes, which, besides forming the body wall, do, of course, give rise to the water-vascular canals and the ambulacral feet. With the old mouth and gullet, other parts of the original larva also disappear, and so it happens that in the starfish it is not all, but only a part, of the larva which passes into the substance of the adult.

On this occasion, we have no space to go into the various forms which the free-swimming larva may take on, for these are very various, and appear in many cases to be very complicated. In the sea-urchins and in the brittle-stars, the sides of the body become drawn out into long processes, and the whole creature becomes absurdly like a painter's easel, for the arms are supported by rods of carbonate of lime which are developed in them. It is, however, necessary to say a very few words as to the larval form of the Rosy Feather-star (*Comatula*), because it displays in an especially remarkable way the intimate relation which subsists between the development of an individual in the present and of a race in the past. This Comatula is one of the last survivors of a group which in the earlier ages of the world was abundantly well represented by a number of the stalked Lily Encrinites. In some rocks these encrinites are exceedingly common, and poetry and peasant lore have woven around them some strange tales, such as that one which Sir Walter Scott refers to in a familiar passage in "Marmion," ii. 16.

In the adult stage this feather-star cannot be said to be very like "St. Cuthbert's beads," for it has not the jointed stalk of its ancient allies, some of which are still found living here and there on the world's surface; but it is very striking to note that, during development, this feather-star of our own seas does pass through a stage in which a stalk is attached to the round, disc-like body of the young, on the side which is opposite to that which carries the mouth (Fig. 6). The illustrations here given will sufficiently well show the very striking resemblance between the young of the form which ceases to be stalked when it reaches maturity and the form which retains its stalk throughout life.

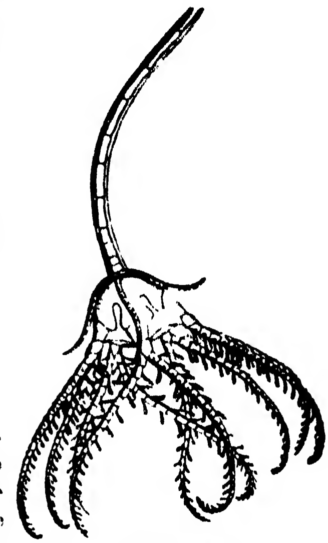


Fig. 6.—A Developing Comatula.

We have now seen that the "radial symmetry" of the starfish is something which is, as it were, secondary. A study of its development gives no support at all to the doctrine that the starfish is a radiate animal like the sea-jelly, and though we find in it some superficial resemblances, we have here only an illustration of the wonderful effect which community of habit or of home has on the most diversely arranged organisms; and, while we are taught to admire the strictness to ancestral arrangements which is exhibited by every group of animals, we learn at the same time that, underlying them all, there is some general disposition which compels them to fight their battle for existence with very much the same weapons and in very much the same way.

SALIVA.

By E. W. von Tunzelmann.

It is a matter of familiar observation to every one that under ordinary conditions of health the interior of the mouth is moistened by a peculiar fluid exuded within that cavity. It is also an equally familiar fact that when the system is disordered by any cause, and more especially when it is fevered, the "mouth is dry"—or, in other words, the moisture is deficient. Finally, proverbial philosophy has embalmed the physiological truism that when the appetite is stimulated by the sight, smell, or thought of some particular dainty, "the mouth waters"—that is, the moisture which is to be the theme of this article is exuded in greater quantities than ordinary. What, then, is this moisture, which it is needless to say we know as saliva, or spittle?

Saliva is especially poured out in abundance during mastication. Accordingly, in order fully to understand its use, and to appreciate its importance as a factor in the process of digestion, we must enter on some preliminary discussion of its composition, its properties, and the causes of its secretion.

There are three pairs of glands concerned in the production of saliva: one, the *parotid gland*, lies on the side of the face, in front of and below the ear; another, the *submaxillary gland*, is placed beneath and somewhat under cover of the hinder part of the lower jaw; a third, the *sublingual gland*, lies in the floor of the mouth, between the tongue and the gums of the lower jaw. Of these three the parotid is the largest: it sometimes becomes swollen and inflamed, producing the affection known as "mumps;" the sublingual is much the smallest of the three. They all have a similar structure, and belong to that class of glands known as the "compound racemose," or much branched. The two larger glands have each a single duct opening into the mouth, which, when traced backwards, is found to branch frequently; the larger ducts are formed externally by fibrous tissue, and are lined by long nucleated or "centre-dotted" cells, which rest on a thin membrane; the final divisions of the duct end in dilatations, called *alveoli*, the walls of which are formed of a thin transparent membrane, lined by large granular cells, with nuclei. Fig. 1 represents the termination of a duct in an alveolus; Fig. 2 represents a duct cut across and several alveoli, and shows well the large granular cells, which nearly fill the cavities of the alveoli, as well as the long cells which line the duct. The numerous alveoli and ducts are held together by connective tissue, in which ramify numerous minute blood-vessels and nerves; the arteries divide into a fine net-work, which is distributed on the alveoli and ducts, and supplies the salivary cells with the material for their secretion.

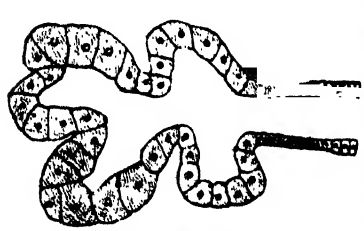


Fig. 1.—Ending of a Salivary Duct in Alveoli (*Highly magnified*). [Slightly diagrammatic.]

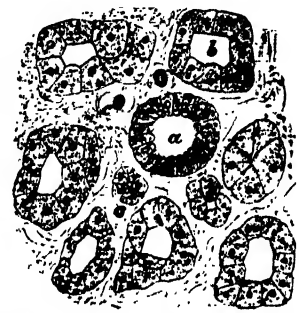


Fig. 2.—Salivary Gland of the Dog —(*a*) Duct; (*b*) Alveolus; (*c*) Blood-vessel. (*Highly magnified from Nature.*)

Saliva taken from the mouth is frothy, owing to the presence of numerous air-bubbles which are entangled in it, but when drawn directly from the duct of (*e.g.*) the submaxillary gland, it is a clear and somewhat viscid fluid, with a slightly alkaline reaction. It is composed chiefly of water, with about five per cent. of solids, among which are common salt, albumen, mucus, &c., and a small quantity of a material called *ptyalin*, which has a peculiar action upon starch. It belongs to the class of bodies called "unformed ferments," substances which have the property of causing chemical decomposition in other chemical substances without themselves undergoing any change; that is to say, the energy which they evoke does not come from themselves. They are to be distinguished from another class of ferments called "formed ferments," which are low organisms which cause in any medium in which they flourish chemical decompositions, which are concomitant with and probably the result of their own vital changes, growth, and reproduction; the unformed ferment exerts its peculiar influence without either increasing or decreasing in quantity. It is to the ptyalin which it contains that saliva owes its most characteristic property—the

power of converting starch into sugar, and to which its value in digestion is largely due. The following experiments will serve to illustrate this property of saliva.

1. Dissolve some starch in hot water, cool the solution, and pour some of it into two test-tubes; to one of the test-tubes add some saliva, then put them both into a water-bath at about 35° C. (95° Fahr.), and leave them in it for about half an hour. Then add to each of them a drop or two of a solution of sulphate of copper, and then a few drops of caustic potash; in the test-tube which contains starch without saliva a blue substance, or "precipitate," will be thrown down, which turns black when boiled. This is the ordinary reaction of a salt of copper with caustic potash, with which the starch does not interfere. In the test-tube to which saliva was added a blue precipitate will also appear, but it will dissolve when more caustic potash is added, forming a deep blue solution; when this is boiled a copious red precipitate is formed. This is a characteristic test for sugar, and proves that some of the starch has been converted into sugar by the action of the saliva.

2. To some solution of starch add a single drop of a solution of iodide of potassium containing iodine; a deep blue colour will appear: this is a characteristic test for starch. Take a small bag made of bladder, or some such animal membrane, pour into it a little diluted starch solution and some saliva, and put the bladder into a large beaker filled with distilled water, then place the whole in a warm chamber, at about 35° or 37° C. (the temperature of the body), and leave it for some hours. Then, on testing the contents of the bladder for starch, as above, no blue colour, or only a slight coloration, will appear, showing that all or nearly all the starch has undergone conversion. If the water contained in the beaker be then tested for sugar, as in Experiment 1, its presence will be readily detected. From these two experiments we learn that ptyalin is most active at the temperature of the body; it is inactive at 0° C., and is destroyed by boiling. The conversion of starch into sugar goes on all the time that the food is being masticated, and probably for a little time after it is swallowed; but as it cannot go on in an acid liquid, it is soon stopped by the acidity of the contents of the stomach. Raw starch resists to a great extent the influence of ptyalin, and the granules must be broken up by cooking in order that the conversion into sugar shall go on to any appreciable extent. From these facts we may arrive at two conclusions of practical importance:—(*a.*) that farinaceous food should be cooked in order to make it digestible; and (*b.*) that the food should be thoroughly masticated and not swallowed too rapidly, so as to allow the saliva time to exert its ferment action on the starch. The importance of this conversion of starch into sugar is evident from the fact that sugar passes readily by diffusion from the alimentary tube into the blood, just as it passed from the bladder into the water in the second experiment above, and so serves to nourish the body; whereas starch is quite unable to diffuse into the blood, so that if from any disease the conversion into sugar is stopped, the starch which is eaten passes out unchanged in the excreta, and is wasted, while the body suffers for want of the sugar.

As we have said, the conversion of starch into sugar ceases in the stomach; but when the food has passed from the stomach into the small intestine it re-commences, and is carried on to a much greater extent than in the mouth, under the influence of a ferment which is contained in the secretion of a gland—the pancreas, or sweetbread—which resembles a salivary gland in structure; the pancreatic secretion has, however, other functions besides the one which we have mentioned, and so differs from saliva.

A similar conversion of starch into sugar is observed in plants—*e.g.*, starch is deposited in seeds as nutriment for the use of the young plant, and as it is insoluble in cold water there is no danger of its being dissolved out by rain, &c., before it is required. When the seed begins to germinate a ferment, called *diastase*, resembling ptyalin in its properties, is developed, which converts the insoluble starch into soluble sugar, and renders the stored-up nutriment available for the use of the young plant. This is what takes place in malting; as soon as the greater part of the starch of the barley has been converted into sugar by the diastase, the young plants are killed by heat, and thus the brewer obtains cheaply a large quantity of sugar, which he converts by fermentation into the alcohol which is present in beer.

Another use of saliva is evidently to assist in deglutition. The watery and mucus-containing fluid converts the often hard and dry food into a semifluid mass, which easily slips down the gullet without abrading the soft surfaces over which it has to pass. In some animals—*e.g.*, the horse, cow, and other herbivora—this is its chief function, and in the dog also the saliva has very little action

on starch. Evidently the power of converting starch into sugar is not developed in the saliva of the dog and other carnivorous animals, because they do not consume much farinaceous food, nor in the saliva of herbivora, because they eat their food raw, and, as we have seen, ptyalin has very little action on raw starch. Saliva is also of use in being adjuvant to the sense of taste; the terminations of the nerve of taste can be affected only by substances in solution. This is why solid substances which are not soluble in saliva appear tasteless; whereas common salt and sugar and similar substances, which are very soluble, are very readily tasted.

Another question now arises: How is it that saliva is secreted in quantity only when it is required to assist in the digestion and deglutition of food, and not continuously? The answer is that the amount and rate of secretion are regulated by the nervous system, in accordance with the needs of the body, by means of the following mechanism, which, though already touched upon in another paper,* may be briefly explained so far as it affects our subject. The anterior two-thirds of the surface of the tongue is supplied by the lingual nerve, which endows the tongue with its delicate sense of touch; the posterior third is supplied by the glosso-pharyngeal nerve, which supplies the tongue with its sense of taste: both these nerves convey impressions from sentient surfaces *to* the brain, and so are called *afferent* nerves.† The submaxillary gland, to which for the sake of simplicity we will confine our attention, is supplied by the chorda tympani nerve, a branch of the facial; this nerve conveys impulses *from* the brain, and so is called an *efferent* nerve. When one or both of the afferent nerves is stimulated, impulses pass along them to the brain, where they are, as it were, reflected down the efferent nerve to the gland, causing it to pour out its secretion into the mouth. The diagram (Fig. 3) will help to make this clear. If the afferent nerves be cut or injured, stimulation of the surface of the tongue can no longer cause a flow of saliva, because no impressions can then reach the brain from the tongue. Similarly, if the efferent nerve be cut, stimulation of the tongue produces no effect, because impulses cannot reach the gland. Thus the secretion of saliva is seen to be what physiologists call a *reflex action*, and, like reflex actions generally, it can and does take place entirely independently of consciousness; it can even be produced in a decapitated animal, immediately after death.

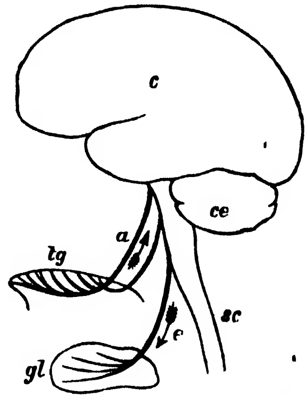


Fig. 3.—Diagram to illustrate the Reflex Mechanism of Secreting. (The arrows show the paths of the impulses.)

(a) Afferent Nerves; (e) Efferent Nerve; Cerebrum; (ce) Cerebellum; Cord; (tg) Tongue; (gl) Gland

The usual stimulus of the surface of the tongue is the food, but anything which acts as a stimulus will cause a flow of saliva; this explains the well-known fact that the dry and parched condition of the mouth which causes such discomfort to a person suffering from thirst can be relieved by sucking a pebble, a bullet, or some such hard object. A flow of saliva is often caused independently of any impressions reaching the brain along the afferent nerves by impulses originating spontaneously in the brain itself, and descending the efferent nerve to the gland; such spontaneous impulses are due to emotions, the thought or sight of food, &c., and they cause the well-known phenomenon of "watering of the mouth" Sometimes the nerve of smell or the nerve which goes to the stomach may act as an afferent nerve in the reflex action of secreting saliva, as when a savoury smell or a feeling of sickness causes a flow of saliva.

We have thus seen that saliva (1) is of use in swallowing, (2) converts starch into sugar, and (3) assists the sense of taste, and (4) that its secretion is governed by a "reflex nervous" mechanism, over which the will has no control.

* "Science for All," Vol. III., p. 108.

† "Science for All," Vol. I., p. 175.

BENDING A BOW.

By William Durham, F.R.S.E.

THE savage who first invented the "bow and arrow" would certainly deserve a monument to his memory if his name could be known, for he was an undoubted benefactor of his species in applying and bringing to light a property of matter which has in no small degree tended to the advancement of civilisation.

It is interesting to note in a museum the gradual development of some principle of nature in its application to the wants of man either in peace or war. We see, for instance, the first simple bow and arrow gradually increased in power as a cross-bow or arblast worked by machinery, giving its possessor immense advantage in the struggle for existence with the lower animals, or with human enemies. These gradually give place to the more fatally effective muskets and rifles, culminating in the deadly breechloader or in the gigantic 100-ton gun, with its diabolical powers of destruction.

There may seem but little family resemblance between the first and the last of the series, and yet we shall find that the last is but the natural development of the first.

Had it only been however, in the art of war that the principle of the bow had been applied, the right of its original discoverer to apotheosis might with much justice be questioned; but it is one of the compensations of cruel war that it sometimes furthers the development of the arts of peace in a manner no other stimulus could do, and the principle of the bow first introduced in the chase and in bloody strife has had, perhaps, its greatest triumphs in subduing inanimate nature to the use of man. There may seem at first sight but little connection between the flight of an arrow, the music of an opera, the propagation of light through space, and the driving of a steam-engine; but we hope to show that they have all a common parentage, and depend on the same principle or property of matter.

Let us consider, then, the action of the "bow." When we pull the string the bow bends somewhat, and when we release the string again the bow springs back to its original position and shape with considerable force. This is the apparent simple action; the wooden rod we call a bow is bent from its original shape by force, and returns to its original shape again on the force being withdrawn. This property of the bow is called "elasticity;" and because its action tends to restore the bent bow to its original straight form it is further distinguished as "elasticity of form or shape." Elasticity, then, means generally that property of matter in virtue of which it tends to return to its original shape or form after having been deflected therefrom by force.

There are many well-known applications and examples of this elasticity in the arts and in nature. Thus a watch-spring is a thin strip of steel coiled up as a spiral, each little part of which may be considered a bent bow endeavouring to straighten itself, and its elastic force thus acting

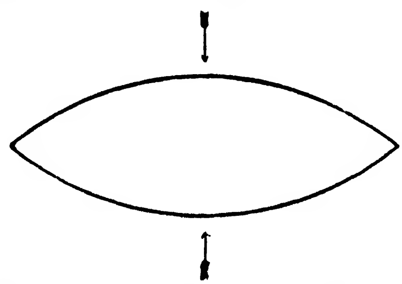


Fig. 1.—Diagram Illustrating the Action of Carriage-springs.

gives the necessary motive power to the machinery of the watch. Carriage-springs also act on the same principle, only in rather a different manner. While a bow's efficiency depends on its resistance to bending, carriage-springs depend on resistance to straightening. They are made originally bent, as in Fig. 1, and the load tends to strengthen them by pressing inwards in the direction of the arrows, and the elasticity of the steel acting against the load tends to preserve the original bent form. Many hard and apparently rigid bodies, such as glass, marble, and ivory, exhibit elasticity in this form; thus, if we take balls of these substances, and let them fall on hard ground, we know they rebound from the ground, and rise in many cases nearly to the height from which they fall. The cause of this can be shown to be due to an action somewhat similar to a carriage-spring; the point of collision is flattened somewhat with the force of the fall as in Fig. 2, where A B represents the flattened portion of the spherical body.

The elasticity tends to restore this flattened

portion to it original form, and the reacting spring repels the body upwards again. With a yielding substance, such as india-rubber, we may observe directly this flattening, but with hard bodies we can only do so indirectly. By sprinkling the surface of the ground with some light powder before letting the ball fall, we can notice that the powder is removed, not at one point only (which would be the case if the ball did not yield in the least), but over some appreciable space. We can easily see the difference elasticity makes in the rebound by dropping side by side an ivory ball or a marble and a ball of lead, which has small elasticity; the rebound of the former will be many times greater than that of the latter. It is this property that makes ivory balls so indispensable in such games as billiards, where much depends on the rebound of one ball from another. We owe many of our comforts also to elasticity. Thus, the comfort of our sleeping hours largely depends on the elasticity of the springs, or of the horsehair or wool of which our mattresses are formed. We might multiply illustrations, but what we have pointed out will suffice to show how widespread and useful this principle of the bent bow is.

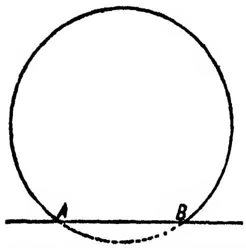


Fig. 2.—Diagram Illustrating the Elasticity of Hard Balls.

In considering more closely the simple action of the bow, as we have described it, we shall find that it is more complex than at first appears. Thus, suppose the annexed Fig. 3 to represent a part of the straight bow divided by parallel perpendicular lines at equal distances (A), it is evident that when the bow is bent these lines will be no longer parallel, but, so to speak, crushed together on the concave or inside of the bow, while they will be drawn apart on the outside as in the annexed figure, like the stones in the arch of a bridge (B). From this we conclude that when the bow is bent the fibres of the wood must be compressed on the inside and stretched or expanded on the outside. That this is so, we can easily see by taking a small branch with the bark on and bending it as a bow, when the bark will be crumbled or crushed on the inside and stretched on the outside. When the bow, therefore, springs back to its original form there will be an expanding of the fibres of the wood on the inside and a contracting of those on the outside. It is really, therefore, to this resistance of the fibres of the wood to expansion and contraction that the power of the bow is due. Now this stretching and compressing of the fibres of the wood enlarges our field of inquiry, for we find many substances whose elasticity cannot very well be exhibited as a bow, but which can be readily seen on stretching or compressing. We have a very familiar illustration of this in india-rubber, which we can stretch to many times its original length, compress, bend, or twist in various ways without permanently altering its shape. Jellies also exhibit similar phenomena in a very marked manner. It is to be remarked, however, that, although we can stretch, twist, or bend these two substances with the greatest ease, it is extremely difficult to compress them all round so as to make them occupy less space.

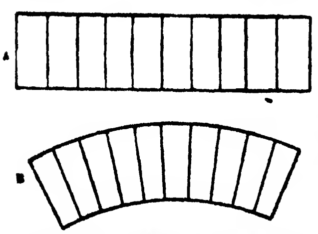


Fig. 3.—Diagram Showing the Effects of Bending a Bow on the Wood of which it is made.

The elasticity of metals is very well shown by their resistance to extension and their tendency to return or contract to their original length. Thus, if wires of different metals be suspended by one end and weights attached to the other end, they will be stretched in various degrees, and, if the weights be not too great, contract to their original lengths on the weights being removed. Investigations conducted in this manner have proved that all metals are possessed of elasticity to some extent. Iron and steel, for instance, will return to their original length after very considerable stretching, while lead, on the other hand, only exhibits this property within very narrow limits. There is yet another form in which elasticity may manifest itself in cords and wires. If we fix firmly one end of a wire or cord and twist the other end round as we would turn a screw, the wire or cord on being released will untwist itself again. This is called "the elasticity of torsion." Now, if we firmly fix a wire or cord at both ends and draw it by the middle of its length to one side, we can easily see that we stretch it or make it longer, as in Fig. 4, so that when we release it again it returns to its original length by virtue of its elasticity contracting it; and, further, when we release such a cord, wire, or a bent bow, none of them returns at once to its original position or form, but vibrates from one side to the other of that position for some time

before coming to rest, much in the manner of a pendulum swinging backwards and forwards. Now, as our musical stringed instruments depend on this vibratory action of wires for their efficiency, we see that the same property of matter which gives to the arrow its flight gives us the sweet music of the harp or the piano.

Fig. 4.—Diagram Illustrating the Effect of Stretching a Wire.

In all the cases we have mentioned there is a limit beyond which the elasticity does not act, and if that limit is exceeded the body either breaks or has its shape permanently altered. Thus, if we bend a bow too much it breaks, or if we stretch or twist a wire too much it becomes permanently lengthened or twisted. The study of this limit is therefore of great importance in the application of metals and other substances in machinery, bridges, and other structures, because if this limit is exceeded in the strain which these have to bear, serious consequences may ensue from their permanent distortion.

When we bend a bow or stretch india-rubber or wire we do not *necessarily* alter the bulk or volume of the substance, because when we lengthen its form in one direction we may shorten it in another; thus, a stretched wire becomes of less section or thinner. This is well seen in india-rubber, where the contraction in breadth exactly compensates for the extension in length, and the volume remains almost exactly the same. In such cases we merely alter the shape or form. We may, however, by compression on every side—as, for instance, by squeezing or crushing a sponge in the hand—reduce the volume or bulk of a substance, and if the substance regains its original volume on being released we call the elasticity exhibited "elasticity of volume," to distinguish it from "elasticity of form," which we have hitherto considered. There is really, however, no difference in the principle of the two forms, and they are separated only for convenience of study. Solid bodies possess this elasticity of volume only to a very small extent. Thus wires, on being stretched, very often have their volumes permanently altered. Coins also have their volumes diminished by the process of stamping. Fluid bodies, on the other hand, possess this form of elasticity in a very marked degree, while they are devoid of the elasticity of form entirely—having no tendency to maintain one form more than another. Liquids such as water possess elasticity of volume very perfectly, so far as experiments have gone, regaining exactly their original volume after compression. The pressure required, however, to alter the volume is very great indeed; thus, in the case of water, a pressure of 2,000 atmospheres, or thirteen tons, to the square inch reduces its bulk by only $\frac{1}{11}$th part. We cannot say, in the absence of experiment, whether any amount of pressure would permanently alter its volume, or if, in other words, there is any limit to its elasticity.

The most perfectly elastic bodies, however, with which we are acquainted are the gases, so far as volume is concerned at least. We may compress them to any extent we please, with one limitation, to which we shall afterwards refer, and they will at once regain their original volume on the pressure being removed, and, further, as the bent bow, on being released from its constrained position, regains its original shape with considerable force, so gases, on expanding to their original volume, do so with a pressure or force depending on the extent to which they have been compressed. Thus, if a gas is reduced to half its bulk or volume, its pressure or tendency to burst outwards is doubled, and so on. From the large volume which gases ordinarily occupy, and the great range of their elasticity, they are of the greatest service to man, for it is evident that, by a suitable amount of compression, we can store up, so to speak, any amount of force, which can be liberated at once and made to do work in many ways. In the case of the bow, the limit of power is soon reached, because, although we may increase its power by increasing its dimensions, yet practically we cannot go beyond a certain extent, as it becomes cumbrous and unwieldy; gases, on the other hand, can be compressed into the smallest bulk, and the smaller the bulk the greater the effect of the elasticity when they are released from constraint. It was, then, a great, but at the same time a most natural advance when man passed from the use of the elasticity of solids to that of gases in his weapons of war. The advance would not have been so great had man depended on his own mechanical power to compress the gases, because he would have required to have expended as much power in compressing the gases as he would have gained by their elastic expansion, according to the well-known laws of the "conservation of energy;" but he called to his aid two powers of nature, which greatly added to the value of elasticity. These powers are chemical affinity and heat. Thus, in gunpowder, the molecular and

chemical forces of the charcoal, sulphur, and nitre hold in control the elastic forces ready to be displayed the instant a spark is applied. They act in a manner analogous to the catch which holds the cord of the cross-bow, keeping the bow bent, but which can be instantly released, when its elasticity is free to do its work. The heat also developed when the gunpowder is fired adds immensely to the elastic force of the gases generated. Thus we see that the modern weapons of war depend on the same property of matter as the ancient and simple bow.

The fact that we have mentioned, viz., that heat adds immensely to the elastic force of gases, widens the sphere of its application. Thus the vapour of water or steam, which differs but little in its nature from a true gas, has its elasticity greatly increased by the action of heat, and when at high temperature possesses enormous expansive force; and by the mechanical arrangements of the steam engine this force is utilised in driving our machinery or propelling our locomotives and ships. Thus we see that this all-pervading elasticity is of immense service to man in every department of his activity. By its means he fights his battles or weaves his cotton; by its means, also, he keeps note of time, and adds to the comfort of his repose. In a word, it is a universal servant ministering to his wants or pleasures at every turn; and, as we shall presently see, unlocking to the diligent inquirer many of the secrets of nature.

Having considered the property of elasticity so far as it is made manifest to our senses, we must now endeavour to understand the causes of this remarkable power, and to do so we must exercise our mental vision somewhat, as we shall here have to do with facts which are not, and probably never will be, visible to the physical eye. Let us consider first, then, what is the meaning of the fact that we can compress bodies of any kind—say a gas, for simplicity of illustration—into smaller bulk. If we reduce say a foot of gas to the dimensions of only six inches, what does it show? From the constitution of our minds we are compelled to believe that the twelve inches the gas originally occupied were not entirely filled with gas; there must have been empty spaces, or at least pores, in the gas; and the reason why we could reduce the bulk or volume of the gas was, that we reduced the size of the empty space, by pressing the particles of gas close together—just as when we press a sponge on every side we reduce its size by reducing the size of the pores with which it is filled. Now this applies equally to any body, whether solid, liquid, or gaseous. Wherever we can compress such a body into smaller bulk it must be because the matter is not continuous, but has empty spaces to a greater or less extent—invisible, it may be, even to our most powerful instruments, but still there. On no other condition can we conceive of compression being possible. From such considerations it is concluded that all substances are made up of almost infinitely small particles or atoms, and upon the closeness of these atoms mainly depends whether the substance assumes the gaseous, liquid, or solid form. Now we know that *as a rule* heat expands solids, liquids, and gases, causing the former state to pass into the latter if applied with sufficient intensity; or in other words, it causes the ultimate atoms to separate from one another and leave more and more space between them. This is just what we call elasticity; the ultimate atoms separating from one another after being compressed. We have mentioned also that heat greatly increases elasticity, as we might expect. To show this take a bladder half filled with air, and tightly tied up at the neck so that no air can get out or in, and place it before the fire. In a very short time the bladder will swell out and appear completely filled, from the increased elasticity caused by heating the air in the inside. There is thus therefore some intimate connection between heat and this elasticity. Another example of this connection is interesting especially because it is an example of what is not often apparent, viz., heat contracting a substance. Take an india-rubber strap, and suspend it by one end; to the other end attach weights till it is very considerably stretched; then bring near the strap a piece of live coal with a pair of tongs, and pass it up and down close to the india-rubber, which will thereupon contract considerably, raising the weight in so doing. In this case also heat has increased the elasticity of the india-rubber, enabling it to raise the weight, although it contracts the volume instead of expanding it. Also, if we take the strap and hold one end between our lips and draw out the other sharply with the hand for some distance, we shall perceive by our lips that the temperature of the india-rubber is very perceptibly raised. On allowing it to contract again after some little time our fingers even will be sensible of its temperature being lowered. It is not the purpose of this paper to enter into the explanation of this curious behaviour of heat on india-rubber, and it is merely mentioned to show the intimate relation between heat and elasticity. Now, heat has been shown to be a mode of motion. When

a body is at a high temperature its particles are in a state of intense vibration, moving about at a great speed. The particles or atoms of a gas, therefore, which, as we have seen, owes its gaseous form to heat, must be moving rapidly about in all directions. We can understand why it presses outwards; the atoms are almost infinite in number in any small space, and each one striking against the sides of the containing vessel, a constant bombardment, so to speak, is going on; the individual strokes are too minute for our observation, but we recognise the general result as an outward pressure. Further, we can understand how the pressure outwards is increased when the volume is diminished. Suppose the walls of the vessel to be twelve inches apart, and that an atom travels from one side to another in a certain fraction of time, giving one blow at each journey; we can see that if we bring the walls six inches nearer, or half the distance, the atom will deliver two blows for one it did before in the same time, and this is equivalent to doubling the pressure, which we find by experiment to be the case. The reason, then, why the gas springs back to its original volume when the extra pressure is withdrawn is evident; it is due to the motion of the ultimate particles, atoms, or more correctly molecules, of which the gas is composed. If a gas could be sufficiently magnified to make its molecules visible, it would present very much the appearance of a cloud of gnats, which we may see hovering over water or a hedgerow in summer—a mass of small incessantly moving bodies with relatively large spaces between each. Now suppose we compress such a cloud into smaller and smaller space, it would gradually assume the appearance of a solid body, and the spaces between the bodies would at length become invisible, and the movements would be reduced to a kind of vibration. While this process of compressing was going on, we should ca l into play another force. We know very well that all bodies attract one another in some manner; in large bodies such as the sun and earth there is the attraction of gravity, while in small bodies or atoms such as we are considering there are attractions such as chemical affinity, cohesion, &c. When the atoms are at such distances apart as in the case of a gas, these attractions have no sensible effect, but as the atoms are pressed closer these attractions exert their influence, and modify the motions of the atoms, just as, for instance, if the earth were as far from the sun as one of the fixed stars is, the attraction between them would have no appreciable effect; but when they are brought to their present distance their motions are mutually modified, and they no longer require any other force than their mutual attractions to keep them together. Now the molecules or atoms of a gas act in an analogous manner; when in an expanded state the molecules seem free to move away from one another to any extent, but as they come within the distance of mutual attraction so as to assume the liquid or solid form, they lose this freedom of motion entirely, and acquire the property of cohesion, so that it requires force to separate them again. It must be mentioned, however, that the process we have described of compressing a gas into a liquid or solid cannot be accomplished by pressure alone; we must also take away some of the motion of the molecules, or in other words lower the temperature. In every gas there is a temperature above which no known amount of pressure will reduce the gas to a liquid or solid state. In these two forces, then, we have the key to the phenomena of elasticity. There is the expansive force due to the motion of the ultimate particles or molecules, resisting compression and tending to expand the substance under experiment. In a gas the limit of this elasticity is reached when the molecules are so near one another as to be subject to sufficient attractive force to form a liquid, when they no longer tend to resume the original volume. The limit of the elasticity of a liquid may be supposed to be reached when the molecules are so closely in contact as to form a solid, and the attractive force is so strong as to resist change of shape or expansion, so that when forcibly drawn apart the molecules tend to rush together again.

Having thus traced the principle of the "bent bow" through various modifications, and pointed out its most probable explanation, we shall very briefly refer to various natural phenomena on which this principle throws considerable light. Suppose a number of atoms or molecules arranged in a line represented by $a\,a'$, $b\,b'$, $c\,c'$, $d\,d'$, $e\,e'$, &c., and we give the first a a blow or push from left to right, it will pass to the position a', and acting on b will drive this to b', this acting again on c will push it to c', and so on. In consequence of elasticity, these molecules will swing back again to their original position, and beyond it to the right, and will continue this backward and forward swing or vibration for some time after the original blow or push has ceased. Further, the molecule a being first moved may have passed to a', and back again beyond its first position to the left, and be just commencing its second vibration when the movement reaches e, so that e commences its first swing

towards e' when a is commencing its second to a'. In this case the distance from a to e' is called the length of the wave of motion, which is made up of a compression when the molecules swing to the right, and an expansion when they recoil by their elasticity to the left. This vibratory motion, then, is due to "elasticity," and may take place among any number of molecules, or in any or all directions around the centre of disturbance a as well as in a single row in a straight line. Now this form of wave motion is actually what takes place when sound is propagated through air or gas; there are alternate compressions and expansions, and we may extend the application of the same principle to all conductors of sound, whether solid, liquid, or gaseous. Further, it is proved that, other things being equal, the velocity of sound through any substance depends on the elasticity of that substance—being greater where the elasticity is greater and less where it is less. Thus sound travels faster through water than through air, and faster still through solid metal.* We thus see that it is in reality the same principle or property of matter that enables the savage to kill his enemy or capture his game, and enables man everywhere to hold converse with his fellows; without this elasticity of matter the world would be as silent as the grave; the song of the bird, the ripple of the stream, and the sweet music of speech, would be alike unknown. It is not, however, in the propagation of sound alone that elasticity manifests itself, for we know that light and heat are due to a vibratory or wave-like motion propagated by means of an elastic medium, and from this fact we infer with almost certainty the existence of an ether in space, stretching as far as the visible universe at least, and bringing to us the knowledge of distant suns and systems. Not only does elasticity inform us of the existence of this ether, but it tells us also something of its constitution, and opens up a wide field for future inquiry. Strangely enough, this ether most probably partakes more of the nature of a solid than of a gas, as at first we might naturally suppose. Though the heavenly bodies pass through it so freely with apparently no resistance to their motions, yet in structure it must possess a jelly-like rigidity. The proof of this is not difficult to understand. The wave motions in which light is propagated are not, as in the case of sound, condensations and rarefactions in the direction in which sound travels, but are vibratory motions at right angles to the direction in which the light is propagated, and it is easy to see such a motion could not be propagated in a medium of the nature of a gas.

Suppose, in Fig. 5, A A′ to be a column of air or

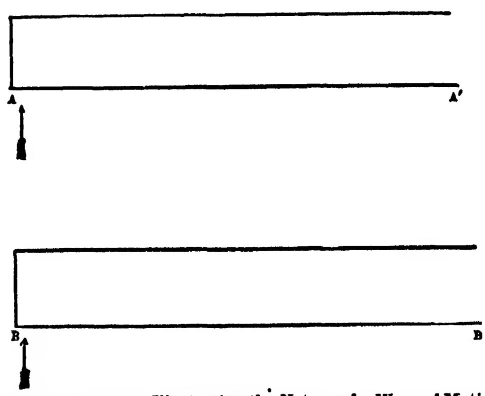


Fig. 5.—Diagram Illustrating the Nature of a Wave of Motion.

gas, and B B′ a metallic or solid rod. Now if we strike the gas upwards at A in the direction of the arrow, it is evident the vibration caused by the blow would not be propagated in a regular manner to A′; the wave of motion would lose its form entirely, owing to the want of cohesion among the gaseous particles. On the other hand, if we strike the rod at B in the same manner, the cohesion of the solid particles would enable the vibration to travel regularly to B′. This is analogous to the propagation of light vibrations, and the medium therefore must have a certain amount of rigidity.

This ether, into a brief consideration of which the study of elasticity has led us, promises to be a wide field for the scientific research of the future. In it probably is hid the key to many of nature's deepest mysteries. Electricity and magnetism are in a fair way to be traced to strains and stresses in its jelly-like substance, and even gravity itself may find its long-sought-for solution in the same source. It is opening out like some new land to the adventurous voyager, seen in dim outline as yet, with here and there a more prominent peak, but giving promise of vast plains and great rivers and mighty forests to be hereafter subdued to the use of man.

* See "Science for All," Vol. I. p. 279, and Vol. III., p. 281, for some remarks on the elasticity of gases and the propagation of sound.

WEIGHING THE EARTH.

By William Ackroyd, F.I.C., etc.

NOT long ago, while the busy merchants of Manchester were keenly bartering on their Rialto, some their cotton, and some their corn, goods arrived and goods to come, the contents of richly-laden ships still on the ocean—they, their goods, and the mighty earth itself, with all that is thereon and therein, were being weighed not very far away. The mysterious operation, making puny and insignificant the weighings effected for the merchant princes of Cottonopolis, was being performed in a dark cellar under the Owens College. This, however, was only the most recent of many such weighings not a whit less extraordinary, for during the last two hundred years the earth has often been weighed, after very different methods, and the results obtained—considering the magnitude of the task, and the ways and means adopted—have been sufficiently near to each other to merit our confidence.

One has a difficulty in realising the immensity of the mass that has been on these occasions, figuratively speaking, put into the scales. In our endeavour to grasp some idea of it, let us follow in imagination those emigrants now leaving Gravesend and bound for the Australian continent. The good ship, freighted with its human cargo, calls at Plymouth, and ere long is passing down the Atlantic Ocean; it ploughs its way through the deep with an average speed of over 200 miles a day, but if we trace its progress on the map we see that it moves, comparatively speaking, much slower than the snail, so slow, in fact, that one could not see the pointer move, which correctly represented the vessel's speed on an artificial globe. Twenty-five days after starting they have reached the Cape, and in thirty days more they have arrived at Melbourne. Day after day they have proceeded at what has seemed to them a quick pace, leaving behind the white cliffs of Albion—perhaps made whiter by a mantle of snow—for the scorching heat of the tropics, and finally reaching, after an excursion of some twelve thousand miles, their new home at the Antipodes. And now to get round the earth we must proceed farther than the emigrants. We accordingly pass down the Bass Strait and enter the vast stretch of Pacific Ocean, then, after very many days, during which we have again and again been delighted with glimpses of the Polynesian islands—oases in a desert of waters—we arrive at the Canal in the Isthmus of Panama, which we will take the liberty of fancying M. de Lesseps has successfully cut through; and now a comparatively short journey across the North Atlantic brings us home again, after about eighteen weeks' continuous sailing. We have circumnavigated the earth, gone round the vast ball on which we live; and now, with a lively conception of its magnitude, let us consider how it may be weighed.

Some idea of how we ought to proceed will be gained, if we consider how it would be possible to weigh without scales one of those big stone balls which top the gate-posts in front of a Cromwellian mansion. A minute inspection of the ball shows us that it is of the same kind of stone as that to be found in a neighbouring quarry. It is easy to ascertain the weight of a cubic inch of this quality of stone, and afterwards by measuring and computation the number of cubic inches which the ball contains. A simple multiplication sum will then give us the weight of the large stone ball. We have similarly to ascertain, in the case of the earth, (1) the number of cubic miles in it, and (2) the weight of a cubic mile of it.

It is a curious fact that the distance round the earth was measured some two thousand years ago by the philosopher Eratosthenes. He regarded the earth as an immovable globe, and he attempted to measure its magnitude in the same way as we do to-day. Imagining the circumference of a great circle *a b c* (Fig. 1) to extend all round the earth and pass through Alexandria, *a*, and Syene, the modern Assouan, *b*, he attempted to find out what number of degrees of this circumference was intercepted between the two places; in other words, what was their difference of latitude. His results taught him that the arc of earth's surface extending from Alexandria to Syene, *i.e.*, *a b*, was about the fiftieth part of the whole circumference; and taking the distance between them and multiplying by fifty, he roughly ascertained the whole distance round the earth, from which one may readily calculate the diameter, and then the solid content. These are the days of exact experiment, and what

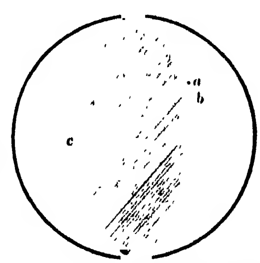


Fig. 1.—Illustrating how the Circumference of the Earth was Measured.

Eratosthenes did roughly we do with the greatest accuracy. Now the length of the line *a b* would be ascertained by very exact trigonometrical methods, so exact that there would probably be an error of two only or three inches in measuring the four to five hundred miles. As the result of calculations, based on accurate measurements of this kind, we learn that, considering the earth to be a sphere, it has a diameter of 7,912·41 miles, and a solid content of 259,373 millions of cubic miles.

We have next to ascertain the weight of a cubic mile of the earth; a matter of the greatest difficulty, seeing that the rocks which compose it are of every degree of density. The surface rocks vary in their specific gravity, most of them being two-and-a-half to three times heavier than an equal bulk of water; and there can be no doubt that the rocks of the interior will become heavier and heavier as we proceed towards the centre, on account of the great pressure of superincumbent strata. It will be apparent, therefore, that the weight of a cubic mile of the earth's substance will vary at the surface with the quality of it; and, further, that a cubic mile of material, say at a depth of twenty miles, will weigh much more than a cubic mile of similar material at the earth's surface. We require then to know some way of ascertaining the *average* weight of a cubic mile of the earth's substance, or, to put the problem in a more convenient form still, we have to ascertain how many times heavier the earth is than a sphere of water of the same magnitude, and of uniform density throughout. There have been some four methods devised for this purpose, and we shall enter into such details concerning them as our readers will readily understand.

A schoolboy is often puzzled to account for the fact that people on the other side of the earth with their feet pointing towards ours do not fall off, and he never fully understands how this cannot happen until he realises that the earth pulls everything towards it, wherever it may be. In virtue of the earth's pull a weight falls downwards from a height with an ever-increasing speed,* and a pendulum swings to and fro until its excursions have become so shortened by friction and the resistance of the atmosphere that it stops. We usually speak of the *force* with which the earth pulls a thing towards it as the *weight* of that thing, and when, in the common operation of weighing goods, we place them in one pan of a pair of scales and in the other place certain standards (which we speak of as hundred-weights or pounds), until the earth's pull on the goods is just balanced by the earth's pull on the standard weights, then we say they have both the same weight, and we measure the weight of the goods by the standards we have employed. Suppose now we were to employ for weighing, instead of the usual pair of scales, a spring balance in which we measure the weight of a thing by the amount it will stretch out a spring, and not by counterpoising it with known standards, we should find a substance with such an instrument to be inconstant in its weight: it would weigh less at the top of a mountain than it would down at the bottom of a valley. It is very evident that the quantity of matter in the substance would remain unaltered during its transit from the top to the bottom of the mountain, although its weight increased. The quantity of matter in a body is spoken of as its *mass*, a very short and convenient word. It will now be perceived that change of position alone will not alter the mass of an article, although it may very materially alter its weight or the force with which it is pulled towards a planet. Here is a fanciful example to the point. There goes a "jolly fellow" who weighs sixteen stones if he weighs a pound; in other words, the earth pulls at him with a force which would register sixteen stones, if he were put into the pan of a very large spring balance. Suppose him now, if it were possible, instantly transported to the surface let us say of Jupiter. His mass would be unaltered, but upon sitting once more in the pan of the spring balance he would weigh 39 stones and 9 lbs.!

This pull, or attraction, is something universal. The sun pulls at all the planets around it, the planets pull at the sun and at each other, and every particle of matter in the universe pulls at every other particle with a force whose direction is that of the line joining the two, and whose magnitude is proportional to the product of their masses divided by the square of their distance from each other. In the case we have just given, the reader will readily see now how the result was obtained. Each planet pulls at a thing on its surface as if its own mass were concentrated to a point at its centre. From the centre of Jupiter to its surface is eleven times longer than from the centre of the earth to its surface, hence the attraction on the man at the surface of Jupiter would be $\frac{1}{11^2}=\frac{1}{121}$th of the pull on him at the surface of the earth. But the mass of Jupiter is 300 times more than the earth's, therefore, so far as mass is concerned, its pull would be 300 times greater, or $\frac{300}{121}$ths. Now the pull on the man on the earth being sixteen stones,

* "The Fall of a Stone," "Science for All," Vol. III., p. 226.

on Jupiter it will be $\frac{400}{161}$ths of sixteen stones, *i.e.*, about 39 stones 9 lbs.

It will now be fully understood that the earth's pull on things at or near its surface may be modified by various circumstances of position. We shall here consider three cases: (1) how a plumb line may be pulled out of the perpendicular; (2) how the weight of a pound of lead may be increased; and (3), how the number of swings of a pendulum of constant length may be altered.

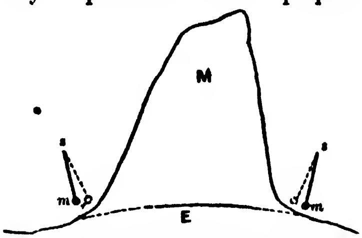


Fig. 2.—Illustrating the Pull of a Mountain on a Piece of Lead (m) near it.

(1) If a weight m (Fig. 2) be attached to a string and suspended from a fixed point, s, the string points towards the centre of the earth. The great mass of the earth, E, pulls at the small mass, m, in that direction, but a mountain, M, close by will exert its attraction on the weight m, and draw it a little towards it, so that the plumb-line no longer points to the earth's centre. Ordinary methods of observation here altogether fail us, and it is only by sidereal observations made with extreme care that the effect has been noted and measured. Chimborazo caused a deviation of 11″, according to Bouguer and La Condamine; the sum of the deviations caused by Schiehallien in Scotland on opposite sides of the mountain was 11″.6 in the observations of Maskelyne; and Sir Henry James obtained a joint deflection of 4″.21 caused by Arthur's Seat near Edinburgh.

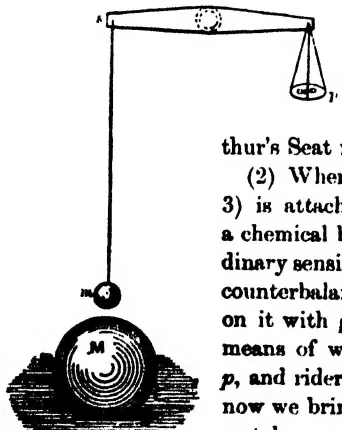


Fig. 3.—Illustrating the Weight of a Ball (m) increased without adding anything to it.

(2) When a weight m (Fig. 3) is attached to one end of a chemical balance of extraordinary sensitiveness (s), we can counterbalance the earth's pull on it with great exactness by means of weights in the pan, p, and riders on the beam. If now we bring a heavy mass of metal, M, directly under m, the pull of M is added to the earth's, E, in other words the weight of m is increased. Mr. J. H. Poynting made the experiment, and with a weight, m, of nearly 1 lb. (452·92 grammes), and a large lead mass, M, of 340 lbs. (154,220·6 grms.) the weight of m was increased by $\frac{1}{11,000,000}$th. The series of experiments were made with great care in Owens College, Manchester.

(3) A pendulum consists of a bob, m, suspended from a point, s (Fig. 4). By lifting the bob to m' and letting go, the earth pulls it downwards, and in virtue of this pull it swings down to m and continues its progress to m''; it then proceeds over the same course backwards, and repeats the to-and-fro motion until it is stopped by the resistance of the air and friction at the point s. If the pull on m is decreased, the speed of the pendulum will be slackened, and this in a way which will give us a measure of the exact amount of decrease of the pull. A pendulum that makes 86,535 vibrations in a mean solar day in London will make only 86,400 at the equator in the same time, because the pull in the latter position is less than at the former, and a simple calculation with these figures shows us exactly how much less.

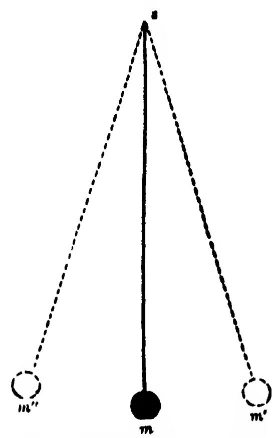


Fig. 4.—The Swing of a Pendulum.

What would be the effect if we took the pendulum down a pit? Newton has shown that any particle of matter, b (Fig. 5), within a sphere is equally attracted in every direction by all portions of the external hollow shell, M M, just inside which it rests, and the pull of this shell on the particle may therefore be neglected. Let a b represent the shaft of a pit; a pendulum vibrating at its mouth, a, will make a certain number of vibrations in a given time, the result of the whole earth's pull upon its bob; but at the bottom of the shaft the bob of a perfectly similar pendulum will be pulled by only the internal sphere, E; and if the earth were homogeneous throughout, the number of vibrations would be reduced in this position. The earth, however, is not of uniform density, and such are the conditions that the internal sphere, E, which attracts the pendulum at b, does so with

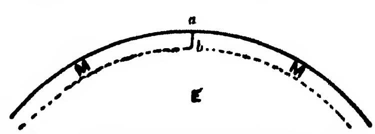


Fig. 5.—Illustrating the pull of the Earth on a Particle within it.

more force than the whole earth attracts *a*. There is thus an increase in the number of vibrations at the bottom of the pit. The Astronomer Royal has made several attempts to get accurate quantitative results, and, unlike the ordinary run of calm astronomical observations, his experiments were not unattended with danger. The first two attempts were made at the Dolcoath mine in Cornwall, but both failed; the first on account of his instruments being destroyed in the shaft, and the second because of the subsidence of a huge mass of rock, which brought the experiments to a sudden and premature conclusion. Nearly thirty years after, a third attempt was made at the Harton Colliery, near South Shields, 1,200 feet deep, and it was completely successful. It was found that a pendulum beating seconds at the mouth of the pit gained 2¼ seconds per day on a similar one at the bottom.

Each of these series of observations furnished data for ascertaining the mean density of the earth—*i.e.*, for telling exactly how much heavier the earth is than a ball of water of uniform density and of equal magnitude. In every instance the influence of a known mass, M, on a lesser mass, *m* (see Figs. 2, 3, and 5), is compared with the earth's influence or pull on it, and then by many and various calculations the earth's density is arrived at. It will give some idea of the labour expended in getting the value of M when we mention that Schiehallion had to be accurately modelled and surveyed, and that the densities of its various mineral constituents had to be ascertained, while in the case of the Harton Colliery experiments, the surrounding country had to be extensively surveyed, the strata had to be studied, and their specific gravities taken.

Towards the end of last century, some remarkable weighings of the earth were made by one whose name is well known in the annals of English science; for, although the Hon. Henry Cavendish (Fig. 6) was, perhaps, the most eccentric man of his time, he was one of the busiest in the search after truth. From his habits unfettered by social or political engagements, and from the accident of birth exceedingly wealthy, he was able to devote most of his time to research, not in one, but many branches of science, so that Biot has well said of him that he was "the richest of all the wise men, and probably also, the wisest of all the rich."* He numbered among his warmest friends the Rev. John Michell, who devised the torsion balance for weighing the earth. Michell died before he could make the experiments, and the apparatus came into Cavendish's hands, who, after improving it,

Fig. 6.—Henry Cavendish. (*After the Portrait by Alexander*)

made the requisite measurements, and communicated his results to the Royal Society in 1798, in a paper entitled "Experiments to Determine the Density of the Earth."

The torsion balance is of exceedingly simple construction, consisting of a horizontal rod, *r* (Fig. 7), suspended by a fine wire from a fixed support, *s*. When the rod is turned round in a horizontal plane the wire is twisted, and being elastic tends to untwist itself. The strength of the pull which turns the rod is proportionate to the angle through which it is turned—*i.e.*, if a certain pull will turn the rod through an angle of 3°, a pull of double the strength will turn it through 6°. If, then, two small metal spheres, *m m*, be attached to the ends of the rod, *r*, it appears not improbable that if larger spheres, M M, be brought near them, as in Fig. 7, some indication may be obtained of the pull which they exert on the lesser balls in virtue of that universal attraction we have already mentioned. When every precaution has been taken to

* "Le plus riche de tous les savans, et probablement aussi, le plus savant de tous les riches."

shield the balls from air currents and other sources of error, it is found that the spheres, M M, have a measurable influence on the swing of the balls, m m,

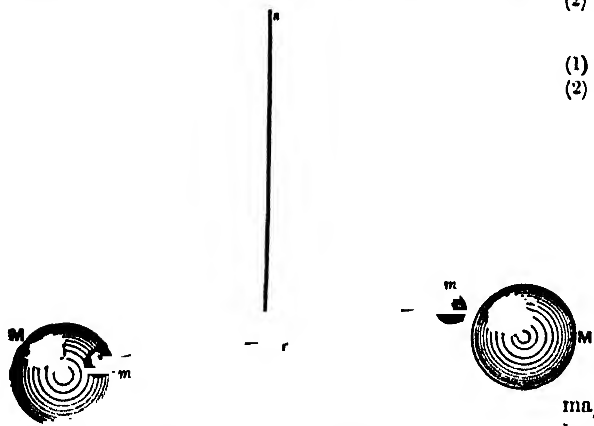


Fig. 7.—The Torsion Balance.

when vibrating, from which it is possible to determine what portion of the weight (*i.e.*, pull of the earth) of either ball, m, is equal to the pull which M exerts upon it. The mass of M is known, and from the other data obtained the density of the earth may be calculated.

We may thus tabulate the results that have been obtained by the various methods :—

	Observer.	Mean Density of Earth Obtained.
Deviation of plumb line :		
(1) By Schiehallion . . .	Maskelyne, 1774 . .	4·713
(2) By Arthur's Seat . . .	Sir H. James, 1855 .	5·316
Vibrations of the pendulum :		
(1) On Mont Cenis . . .	Plana and Carlini .	4·950
(2) At the Harton Coal-pit .	Sir Geo. Airy, 1854 .	6·565
Torsion balance experiments :		
	Hy. Cavendish, 1798	5·448
	Reich, 1837 . . .	5·438
	F. Baily, 1838—1842	5·660
Chemical balance experiments :		
	J. H. Poynting, 1878	5·690
	Average . . .	5·472

This average of 5·472 is not far off 5½—*i.e.*, we may say that the earth is five and a half times heavier than a globe of water of the same size. Taking now the dimensions of the earth as given at the commencement of this paper, it is easy for us to calculate its weight, for we know the exact weight of a cubic mile of water; and the result obtained, according to Sir John Herschel, is 5,842,000,000,000,000,000,000 tons, of 2,240 lbs. to the ton; or expressed in words, the earth's weight is five thousand eight hundred and forty-two trillions of tons!

A RED SEA-WEED.

BY E. PERCEVAL WRIGHT, M.A., M.D., F.L.S., ETC.,
Professor of Botany in the University of Dublin.

A SHORT walk along the sea-shore, or a very casual glance into a still rock-pool, will speedily show us the plants of which we propose to treat. Sea-weeds are mostly of a green, brown, or red colour. In great waving masses among the rocks, they may float like long tresses on the surface of the waves near low-water mark, or, in a more or less damaged condition, may be tossed up at our feet from the depths from whence the winter storms have wrenched them. Floated out over a piece of stiff paper, the more delicate species are among the most beautiful of natural objects. Examined scientifically, their interest is not less pronounced, though the details of structure which the magnifying-glass or the microscope reveals are less complicated than the corresponding details in a flowering plant;* yet once understood, "the flowers of the sea" are even more wonderful in their organisation. The "weed" we have captured from the wave is, say, a piece of dulse or the beautiful *Plocamium*, dear to lady-collectors, the toothed *Odonthalia* or the almost equally common *Griffithsia*—to what class of the vegetable kingdom does it belong? The scantiest acquaintance with botany tells us that it is flowerless, in the familiar acceptation of the term, though we shall find that it is not without organs which serve all the essential purposes of blossoms. The term we have applied to it, is, however, like many popular names, erroneous. We term it a "sea-weed;" and so it is. But the family to which it belongs has representatives in fresh water also. Accordingly, to avoid confusion, we shall call the plant by its technical title—that is, an "alga," for to the great division of "Algæ" it belongs.

From very early times the algæ have been known

* "A Primrose," "Science for All," Vol. II., p. 215.

as a class of plants living either in salt or in fresh water. The limits of this class were not, it is true, ever very exactly defined, but neither are they so defined even at the present day. A century and a half ago Linnæus included among the algæ the club-mosses, the lichens, and the sponges, and we have to come a century nearer to our own time to find the class limited to simple "thallus-bearing plants" able to support themselves without preying upon other organic forms. It may be well here to define what is meant by a thallus; it is an aggregation of cells, forming a vegetable structure in which there is no true distinction between the stem and the leaves, and from which there are no true roots. Such a definition, while, perhaps, about the best that can be formulated, is not strictly correct; for, if leaves be lateral outgrowths from below the terminal growing portion of a stem, then it is not improbable but that some so-called "thallophytes" (thallus-bearing plants) possess them. In progress of time the club-mosses, lichens, and sponges—which are true animals*—were removed from the algæ, and something like a scientific classification made. Endlicher, Lindley, Berkeley, and Sachs have, among others, attempted to arrange the numerous species into a natural sequence. But for our purpose, the divisions of Harvey—albeit he did little more than give new names to the classes of Lindley—will serve. The sub-divisions of this distinguished writer on the group are:—1, Those of a rosy-red or purple, rarely brown-red or greenish-red colour (*Rhodospermeæ*);† 2, Those of an olive-green or olive-brown colour (*Melanospermeæ*);‡ 3, Those of a grass-green or rarely a livid purple colour (*Chlorospermeæ*).§ He excluded the charas, and rightly combined the diatoms with the green algæ. During the last twenty years our knowledge of the algæ has vastly increased, but even yet that knowledge is not quite complete enough to enable a really satisfactory classification to be made.

Until recently, the systems of classification of the algæ were but little more than aids to memory. The student now tries to know all about the modes of growth, and the modes of reproduction of the species belonging to the *Algal alliance* in order that he may group together those having the greatest resemblances in these respects. Until the life-history of all, or nearly all, the species of algæ is known, the last link cannot be put on to the chain that will bind them all together in an orderly sequence. There is, as might be expected, a very great difference in the system of tissues in these sub-divisions. Thus, taking the last first—in it we often meet with forms so simple that even in their mature or adult state they consist of but a single cell; this cell is, however, capable of dividing, and each half thereof will, in process of time, so far as external form goes, resemble closely the cell from which it started. In such a case it often happens that when formed the two halves break from one another, but in other cases after division they will, on the contrary, be found to remain attached, and so give rise to what is called a filament or chain, each cell or bead in which can, and often does, again divide so as to make the filament to elongate itself throughout all and every one of its cells. The protoplasm of each cell having the power of dividing in this way, an indefinite length may be attained by the filament; but it will not thus, it is to be noticed, in any degree add to its breadth or width. These latter developments will be attained only by a vertical cell division which, especially when combined with an onward growth of a special terminal cell, will give rise to a frond-like system of tissues. This special cell-growth is a very important factor in the development of the fronds of the second sub-division of algæ, and in the first it has a good deal to do with the production, not only of the frond itself, but also of its fruit. It is a form of growth very easily observed in many of the simple branching species of algæ.

In the present paper we would confine our attention to the red sea-weeds, and sketch the mode of growth of a red algal form; and to complete its life-history it will then be necessary to give an account of the forms of reproduction to be met with. The example chosen to illustrate the first is *Griffithsia setacea*; that to illustrate the second is one first described by Thuret as *Spermothamnion flabellatum*.

If we examine that pretty and not uncommon British sea-weed *Griffithsia setacea*, which was called after Mrs. Griffiths, one of the ablest investigators of her time of our native algæ, we find it, before it has reached its fruiting stage, to consist of a number of jointed filaments.

If the growing tip of a filament be floated on to a glass slide in a drop of salt water, and covered with a thin glass cover (it should not be subjected to any

* "Science for All," Vol. I., p. 55.

† Nearly equivalent to those algæ with fruits called oogonia (*Oogoniphyceæ*).

‡ Nearly equivalent to those algæ with fruits called carpogonia (*Carpogoniphyceæ*).

§ Nearly equivalent to those algæ with fruits called zygogonia (*Zygogoniphyceæ*).

great pressure), and then be examined under a "one-fourth inch objective" of the microscope, it will be seen to consist of a well-marked cell wall, which will act as its boundary, and the upper terminal portion of which will present a more or less nipple-shaped form. Occupying the cavity within this will be seen the more or less pink-coloured cell contents; often towards the tip of these will be found a portion in which the pink colour will not be very apparent. Gradually, indeed, this will merge into a quite colourless morsel, which will be found just under the apex of the outer cell wall. From a prolonged watching of this same gradually-growing tip, or from the aggregate of a series of such observations on such growing tips, selected at various stages of growth, it would seem that a true growth takes place (at times somewhat rapidly) in the outward cell wall, which thereby increases not only in length, but also in width and general bulk; and cotemporaneously with this there is a proportionally well-marked increase to the cell contents. This increase might be roughly compared to the stuffing of a bolster-case, where the tightest packed portions would be towards the bottom, and the loosest portions would be towards the top; only of course the bolster-case is quite open at the top where it receives the contents, and in the Griffithsia cell the top is closed and the contents get in by a sort of "atomic transfusion."

As a result of this growth of the cell wall, and of the increase to its protoplasmic contents, it happens that the lower, denser, and more highly-coloured portion of the "protoplasm" is greatly added to, and this apparently at the expense of the upper, less dense, and nearly colourless portion; but in reality, by its conversion into the more formed material, which thus is becoming more and more advanced forward, until gradually it acquires its supply of chlorophyll, and becomes fully organised. The upper portion of the protoplasm is not only less dense and less mucilaginous, but at the growing tip it seems to fade into a colourless almost granular material, which seems as if it had not got its full complement of water of organisation. To return, however, to the consideration of the older first-formed portion, which at a certain time and when a certain length thereof seems to have reached a certain stage of its existence, becomes separated into two—an upper and a lower portion—of which the upper is by far the smaller, being often not more than a mere convex-shaped lens-like mass—the top, as it were, of the coloured thimble-shaped body which is included within the nipple-shaped cell wall. This separation can only be at this stage detected by the most careful adjustment of the light, which will show some slight difference at the place where the two surfaces meet. It is not, however, an absolute separation into two perfectly distinct parts, for there still remains a well-marked central portion which connects the upper with the lower part, and which ceases to form a connecting-link between them only at a very much more advanced period of time.

These structures will be better seen, and their peculiarities will be more easily understood, if a portion of a frond just at the stage now described be gradually immersed in weak glycerine. It is a good plan to allow a drop of glycerine placed at the edge of the glass cover to drive the salt water out before it: this will be greatly helped if the exit of the less dense fluid be assisted by a piece of blotting-paper, and when the substitution of the glycerine is successfully accomplished there will not be a single air-bubble entangled. The cell contents will now very slowly indeed contract, and the different portions will be then more distinctly seen. First, there will be the lowermost cylinder of protoplasm, with its flattened poles, of a lovely and uniform pink hue—some specimens kept in glycerine for more than six months have not yet lost their colour, though in the process of time it does fade—next, the delicate tube of pink protoplasm, stretching from the upper portion of this lower mass to the under portion of the upper; and thirdly, this upper mass itself, often flat on its own lower surface, and irregularly convex on the upper surface—though it is noteworthy that this, its outer margin, is often radiate in outline as well as uncoloured, as if it had been torn away in its contracting from the inner surface of the outer cell wall.

Resuming our study of the living organism—the lower cylindrical mass will be found, when carefully watched, and after it has grown to a certain size, to gradually form a cell wall.

Often at a very early stage, after the separation of an apical portion of the cell contents from the mass immediately below them, a very faint line of demarcation will be perceived in the centre of the connecting tube of pink protoplasm: as growth advances this becomes more and more apparent, and the halves are now seen, though touching each other, not to be absolutely joined. If reagents are used, these halves will be at once drawn asunder, and each fully-formed inner mass has then got a top and bottom opening or pore in its cell wall, and in a long series of such masses there will

thus be formed a more or less continuous communication.

These openings are called by Mr. Archer pits; and in a not uncommon exotic sea-weed (*Ballia callitricha*) these pits, or pores, are closed by very characteristic little bodies which he calls "stoppers" or "lids."

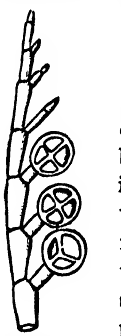


Fig. 1.—Cross-like division of Protoplasm of mother-cell, showing all the four Spores from one view.

Now, all this growth has to do with the individual plant. It keeps on adding cell to cell, branch to branch, filament to filament, and were it to go on indefinitely like this it would, while mindful, as it were, of its own progress, do nothing to add to the number of individuals of the same kind in the world. But the propagation of the species is an important concern of the plant life, and the methods by which it is brought about in these algæ must now be alluded to. They are essentially of two different sorts, one in which the protoplasmic contents of certain cells of the filament divide into four masses, and these not only separate from one another, but eventually escape from the investing cover of their mother cell. These little free-cells are known as "tetraspores." They are simply detached cells, which are endowed with a power when detached of giving origin, by a process of cell growth, to a frond like that of the plant from which they themselves proceeded. These tetraspores in the red algæ are met with of various forms. Sometimes the protoplasmic mass of the mother-cell divides in a crucial way, so that the whole four spores can be seen from any view at once (*Thamnidium*, *Antithamnion*, Fig. 1). Sometimes the division takes place vertically, the spores being then one on the top of the other (*Chondria*, *Corallina*, *Melobesia*, Fig. 2); and again the division may be triangular, and during the growth of the four spores they so arrange themselves as that one of them mounts on the summit of the other three, and only three are visible from the one point of view. This occurs in very many species (*Polysiphonia*, *Griffithsia*, Fig. 3). The tetraspores also vary greatly in situation—sometimes buried deep in the surface of the frond; sometimes found at its very surface; sometimes formed in the terminal cells of a filament; sometimes in internal and lateral cells. Often the mother cell bearing them is stalked; often it is stalkless.

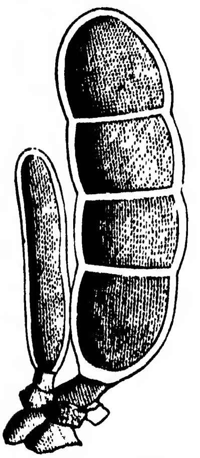


Fig. 2.—Vertical division of Protoplasm, showing the four Spores arranged in a row.

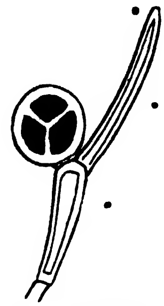


Fig. 3.—Division of Protoplasm, showing triangular arrangement of Spores.

But another sort of reproduction is now to be briefly described. In it two factors combine to form one complete whole. Two cells produce each its own separate mass of protoplasm, but neither by itself is able, when thus separated, to support life or to develop a fresh form. Yet let the two masses mingle, and as a result a new body, the product of the two, is formed, which has all the powers of growth and development. These two cells, which give origin to these two diverse masses of protoplasm, are known as the germ and the sperm cells, and the contents of the latter fertilising the former a new individual is the result. The sperm cells are arranged in clusters, known as "antheridia," and these constitute the male element of the plant. The germ cells form part of the "carpogonium," and this is the female element of the plant.

The antheridia in the red algæ are simple collections of sperm cells—the result of a repeated division of some of the branch cells—sometimes in connection with long hair-like filaments, sometimes quite destitute of these. In *Spermothamnion flabellatum* the antheridia are sessile on the inner surface of its branches. They consist of cellular bodies, in shape oval, oblong, or cylindrical, of a pale colour, and bear a great resemblance to the antheridia in *Polysiphonia;* but, unlike these, the axis of the antheridium does not consist of a filament of large cells, but the entire structure is composed of the same sort of cells. The antheridium consists at first of a filament of three or four cells shorter than the others, and of a lighter colour. The lowermost articulation is longer than wide, the others are wider than long, and are disc-shaped. By the formation of a number of oblique partition walls, the lowermost articulation is successively divided into several triangular cells, which become partially detached; these, in their turn, become once or twice divided, and the cells formed by this last division become the mother cells of the male or sperm corpuscles. Whilst the upper cells of the antheridium divide with pretty much the same

regularity as in the species more particularly described, yet in others these cells, in dividing, leave towards the centre of each a pyramidal cell, which in time forms an axis, as in the case of *Polysiphonia* (Fig. 4). In some very rare cases the masses of

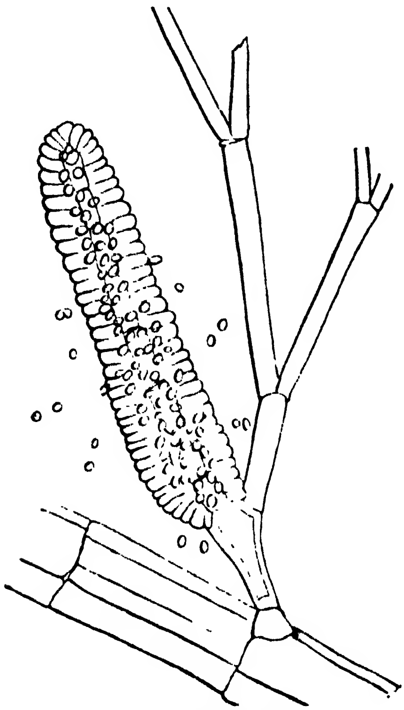


Fig 4.—Antheridium of Polysiphonia.

sperm cells are developed in hollowed-out, pit-like depressions in the frond. This occurs in some of the red algæ with compressed fronds, these made up of several layers of cells. In some (*Gracilaria*) the cavities containing the antheridia are scattered over the surface of the frond, and only open by very minute pores; in others (*Corallina*), the antheridial conceptacles are collected in club-shaped branches, easily perceived, and the orifices partly closed by hair-like projections.

The antheridia are often found growing on different plants from those which develop the carpogonia, and often in the same species not only will these be found on separate plants, but a third form of plant will bear the tetrasporic fruits.

For a very long time the function of the antherozoids—the name given to the male corpuscles—escaping from the antheridia was more than suspected. They were incapable of germination, and therefore could not be spores.

In some species the position and structure of the carpogonium are difficulties in the way of comprehending it, and, indeed, it is only on the living plant that these fruits can be studied with advantage. In the genus *Spermothamnion* the formation of the carpogonium is, however, to be studied with ease, and in the following account of its formation in *S. flabellatum* we follow Bornet. The fruits are developed at the the ends of short lateral branches, which are for the most part made up of four cells, one on the top of the other (Fig. 5). While the first of these does not differ from the other cells of the frond, the three last are remarkable for being short and of a very light colour; the ultimate cell scarcely

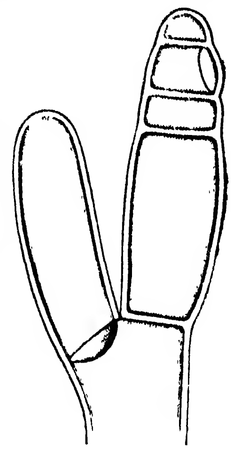


Fig. 5.—First Four Cells of a Carpogonium, penultimate Cell dividing.

ever changes, but the three below it all take a part more or less directly in the formation of the fruit. The lowermost will ultimately produce at its apex a crown of branching, in-turned filaments (Fig. 7), which will form the involucre and surround the ripe spores. The cell just above this will form the peduncle, or stalk, of the fruit, and while it increases greatly in size it does not divide. Lastly, the penultimate cell, by a series of developments, will give rise to the fruit itself. Let us see how this phenomenon begins and ends. Fixing our attention on this penultimate cell (Fig. 5), a portion of the protoplasm towards the outer side will separate by an oblique wall; a second mass will be detached in like manner opposite to the first; then a third and fourth just in the same way, only to the right and to the left. We have now got five cells, one central and four others around this. Of these five, the first to start on its career will become the "trichophoric apparatus" (Fig. 6), that is, the hair-like filament which will receive the contents of the male cell and transmit the influence of those contents. The second cell to be developed, the one opposite to this, ordinarily does not develop farther, though sometimes it will do so. The two lateral cells are those which are the rudiments of the pores, while it is the central cell

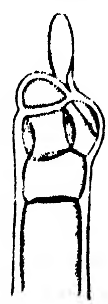


Fig. 6.—Hair-like Cell, or Trichogyne, in Process of Development.

that receives, according to all appearance, the direct influence of the fertilisation and then transmits it to the surrounding cells. At first the disposition of the cells of the fruit-bearing branch is quite regular, but this symmetry is soon destroyed by the unequal development of the surrounding cells. Whilst the cell opposite to the trichophoric apparatus does not increase in size, this latter acquires a length nearly double its first dimensions. The parts contiguous to the central cell and the two lateral cells with it also increase in size, and as a result the whole structure becomes markedly oblique, and the apical cell is no longer to be found on the axis of the branch (Fig. 7).

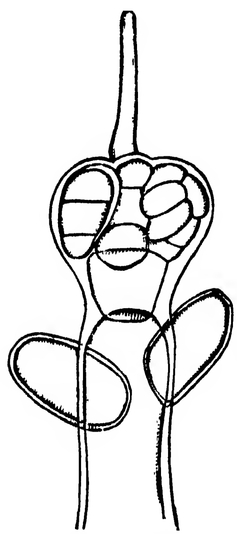


Fig. 7.—Young Fruit after Fertilisation.

At the period of fertilisation the two lateral cells are, as a rule, not at all alike. That one which was separated first will already be perceived to be divided into two by a tangential partition (Fig. 6). If the fruit be not fertilised the cells will stand exactly as thus for some time, but once the male corpuscles (antherozoids) unite themselves with the hair-like cell (trichogyne) these lateral cells will increase in size and divide. The partition walls will be often perpendicular to the axis of the branch, and as a final result there will be formed to the right and to the left of the trichophoric apparatus two little masses irregularly embossed and lobed (Fig. 7). These are at the very first enclosed under the general cuticle of the plant, and while the lobes do not grow much they are covered during their development entirely by it. But as the young fruit grows apace and gets beyond the cell which gave it origin, the lower portion of the mass pushes out and becomes free. The lobe-like processes now increase in size, the outer cells at last giving origin each to a single spore. It is to be noted that both the trichogyne and the trichophoric apparatus are most remarkably persistent in this alga, whereas in most of the Florideæ they fall off very quickly. This very persistence may be a source of error, the more especially in the case of fruits not fertilised, in which some fruitless division may for a little while take place in some of the cells. In a few rare instances the apical cell may become abnormally developed, putting one in mind, on a small scale, of the growth that sometimes carries the flower-stalk beyond the last floral whorl.

Having thus seen the structure of the antheridia and the carpogonia, it remains to be seen how the contents of the one set of cells are conveyed to the other; for it will have been gathered from the above descriptions that the contents of the antheridia are, in a manner, actively discharged from their mother cells; whereas the contents of the carpogonia are, on the contrary, prior to fertilisation, quite passive, and only when the carpospores are ripe do they escape from their fruit-like investment. The recently-discharged antherozoids have been studied in comparatively few species of red algæ. In most of those investigated, they appear as a very minute mass of protoplasm (Fig. 4), destitute of a cell wall, and destitute of any well-marked power of locomotion. I believe that in some cases I have witnessed "amœbiform movements" in antherozoids—that is, creeping movements effected by a prolongation and contraction of their unwalled-in protoplasm. In some cases Bornet figures the existence of cilia *-like prolongations, but even in these there was no ciliary movement. The number of antherozoids discharged from the antheridia is enormous, probably many hundreds for every carpogonium fertilised. And when these escape in flocks, it will be remembered that they are wafted to and fro by the outgoing and the incoming tides, as well as by local currents. And, in addition, it will not be forgotten that coursing about over and above the algæ, seeking what they can get to devour, are numberless species of tiny crustacea (*Edriophthalmia*; *Entomostraca*) and worms, which, doubtless, must often help unknowingly to whisk the antherozoids into the region of the carpogonia. Dr. Dodel Port is, however, inclined to ascribe an even more intimate relation between some of the infusoria and the fertilisation of the Florideæ. He seems to think that, without doubt, in the case of Polysiphonia, several little infusoria (*Vorticella*,† *Epistylis*, *Vaginicola*) facilitate the conveyance of the antherozoids to the trichogyne, and that they thus act in accordance to a natural law, in the same way as do the pollen-collecting bees, who by visiting some flowers assist in their pollenation. Dr. Dodel Port gives a figure of an undeveloped carpogonium of *Polysiphonia subulata*, with its trichogyne. On the

* "Science for All," Vol. I., p. 59; Vol. III., p. 303.

† "Science for All," Vol. I., p. 41; Vol. II., p. 90

cell of the frond hard by there is figured a species of vorticella—its simple stalk slightly coiled, its ciliary apparatus hard at work, and with a precision that bids fair to deprive itself of its coveted food it whirls in a vortex the antherozoids about, causing them finally to impinge right on the edge of the trichogyne. It would be easy to conclude that such an event could sometimes happen, and we have the word of so excellent an observer as Dr. Dodel Port to the effect that he has seen it; and so have we ourselves, but then the specimen was confined within the narrow limits of a thin glass cover, and there was no ebb and flow of tide to interfere with the process, and we are more inclined to think that what the wind is to many flowering plants so is the water to our red sea-weeds with motionless or nearly motionless antherozoids.

The red algæ are found all around our shores. There is scarcely a spot that will not yield some few forms. They are easily collected. Most of the simple filamentous forms will keep in confinement for months, especially in cold weather and when not exposed to the heat of the sun. In spite of all the labours of many workers for the last twenty years, they, as living forms, present a wide, a charming, and an almost new field for observation, in which all, strong and gentle, may help. This sketch of their growth and their form of reproduction is merely meant to lift the curtain, and to show what treasures of knowledge lie behind it.

A COCKROACH.

By F. Buchanan White, M.D., F.L.S., etc.

I SUPPOSE there are few, if any, persons who are ignorant of the existence of the little animals commonly, but erroneously, termed "black beetles" (Fig. 1), and yet how many are there—outside the ranks of professed entomologists—who perceive in this "black beetle" anything beyond a loathsome and destructive beast! Take a lighted candle and, treading softly, go at midnight to the regions sacred during the day to the cook. Over the floor glide numerous dusky forms. They are "only black beetles"—insects destructive, evil-smelling, altogether unattractive. However, if one or two are captured, and killed by being dropped into a cup of boiling water, we shall soon learn by a study of their bodies that even the poor beetle that we tread upon is capable of imparting useful lessons in zoology, anatomy, and the laws of geological and geographical distribution. Turning out our captures on to a sheet of blotting-paper, we will notice that they are of various sizes, and of a shining very dark mahogany or chestnut colour above, but rather paler below; so whether they are "beetles" or not, they are certainly not black. Then we will observe that of the largest specimens, some have leathery wings lying on the top of the hinder three-fourths, but not reaching to the end, of the body; while in others, the hinder three-fourths of the body are uncovered, and the leathery wings are only rudimentary. The latter, as we will learn presently, are females (Fig. 1). Looking next at the smaller specimens, it will be seen that beyond having no wings or rudiments of wings, they do not differ very much from the larger examples except in size; and if we have been judicious in the selection of our specimens we will find that they are of all sizes, from quite small up to nearly the magnitude of the winged individuals. These small ones we may rightly imagine to be the young ones in various stages of growth (Fig. 1). Now we know

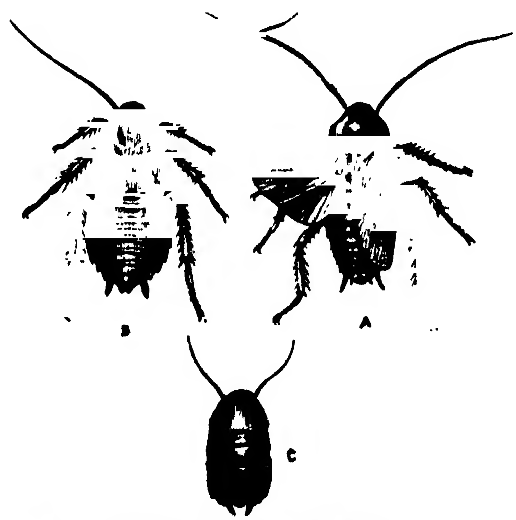


Fig. 1.—A Cockroach. Male (A); Female (B);

(or ought to know) that beetles in the young or preparatory stages are not the least like the mature beetle, but are, after they have emerged from the

egg, first in the form of maggots (of which the wire-worm and meal-worm are familiar instances), and afterwards in that of a quiescent chrysalis or pupa. Our "black beetles" therefore are not beetles at all, and we have ocular demonstration that they are not black. What then are they?

Take one of the individuals with wings, and examine him. When placed with his legs under his body, the head will be almost hidden below the roundish shining plate which covers the upper part of the front part of the chest, and is technically known as the "pronotum." In front of this a little bit of the head projects, but the greater part of it is tucked underneath and rests against the front part of the chest, so that to see it we must turn our capture on to his back. If you have a magnifying glass, a pair of fine-pointed forceps, and a stout needle, they will be useful in the examination. The part of the head now exposed is—though, when the animal was alive, directed downwards—the upper surface. On each side are the large kidney-shaped compound eyes (Fig. 2, A, c), the surface of each of which is composed of a number of six-sided facets. Close to the inside of the eyes are inserted the thread-like many-jointed antennæ, as long or longer than the body. Immediately above the insertion of the antennæ is a small yellow mark on each side, which is supposed by some authors to indicate the place where the simple eyes ought to be. The mouth and organs of mastication, which occupy the narrow apex of the head, are rather complex in structure. From the point of view in which we are looking at the insect, the most conspicuous part is the entire upper lip or *labrum* (Fig. 2, C, *a*), below which, on each side, lie the strong horny mandibles, or upper jaws, toothed at the tip and on the inner surface: these, it must be remembered, do not work perpendicularly as our jaws, and those of all warm-blooded animals do, but horizontally (Fig. 2, C, *b*). Below the mandibles, though scarcely visible from this point of view, lie the maxillæ or lower jaws (C, *c*) but their palpi or feelers can be easily seen, as they extend considerably on each side of the head.

To see the rest of the structure of the mouth, we will have to cut off the head and examine the under-side (Fig. 2). Viewed from below the parts of the mouth are as follow:—At the base a somewhat square-shaped middle plate, the chin or mentum, close to the back part of which, and hinged to the side of the lower surface of the head, is situated on each side one of the above-mentioned maxillæ or lower jaws. Each maxilla consists of four joints, of which the basal one is called the *cardo*, and the second, which is articulated to it at right angles, is the *stipes*. At the apex of the stipes are two lobes or joints, of which the outer one (the *galea*) is soft, and serves as a shield (though probably an organ of sense) to the curved inner lobe, whose inner edge is sharp and toothed so as to adapt it for cutting. To the

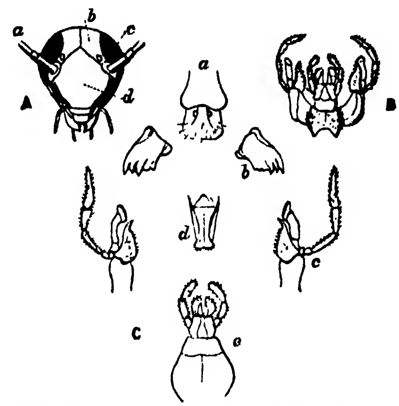


Fig. 2.—Head and Mouth-Organs of Cockroach, *Periplaneta (Blatta) Orientalis*. (After Griffith and Henfrey).

A, Head (*from before*):—*a*, Antennæ cut off; *b*, Epicranium; *c*, Eyes; *d*, Clypeus; B, Under portion; C, Mouth-Organs:—*a*, Labrum; *b*, Mandibles; *c*, Maxillæ; *d*, Internal Tongue; *e*, Labium.

outer angle of the summit of the *stipes* is articulated the five-jointed maxillary palp. At the apex or free end of the mentum is the *labium* (C, *e*) or lower lip, bearing on each side the three-jointed labial palp, attached to the summit of a small piece called the palpiger or palp-bearer. The apical half of the labium is divided into two lobes which constitute the *ligula*, and each of these two lobes is again divided at the apex into two smaller lobes. It is considered, and it seems very probable, that the labium and its appendages are in reality a somewhat altered and coalesced pair of jaws (similar to the maxillæ), such as we find in an unaltered condition in the Crustacea (or Crab and Lobster family).

These then are the external parts of the mouth, the internal arrangements of which we will presently consider.

We have already seen that the young (Fig. 1) resemble (except that the wings are absent) their parents very much, and we have just discovered that the parts of the mouth are constructed for biting, and not for sucking. Now if we leave out of the question those orders of insects which are never provided with wings, namely the *Collembola* and *Thysanura* (the Springtails), and the *Mallophaga* and *Pediculina* (various families of lice), we will find that our "black beetle" must belong to the order *Orthoptera* (so called from the straight

manner in which the wings of most of the species are folded), which includes, in addition to the cockroaches, the grasshoppers, locusts, crickets, stick-and-leaf insects, and earwigs. In the structure of the mouth the Orthoptera resemble in many respects the orders Coleoptera (beetles), Hymenoptera (bees, wasps, ants, &c.), and Neuroptera (caddis-flies, white ants, &c.), but all these undergo what is called a *complete metamorphosis*, *i.e.*, in their preparatory stages they are very unlike what they are in the last or perfect stage. In having an *incomplete metamorphosis* (*i.e.*, as has been already said, the young closely resembling their parents at all stages of their growth) the Orthoptera come near the Hemiptera (or bugs), but the latter have a very differently constructed mouth, never fitted for biting, but for piercing and sucking.

To return now to our cockroach. As in other insects the body of the cockroach may be said to consist of three chief parts, the head, the chest or thorax, and the abdomen or hind body.

We have already examined the external structure of the head, so need not go over it again.

The chest or thorax we can first examine in a young one, and then see how it is modified in the perfect insect. It is made up of three rings, segments, or somites, to the under side of each of which is attached a pair of legs. Each leg (Fig. 3) consists of five parts; at the base is the *coxa*, with a smaller piece, the *trochanter*, between it and the thigh or *femur*, following which is the *tibia*, bearing the six-jointed *tarsus*, the last joint of which is provided with two curved and sharp claws. Each pair of legs is alike, though differing in size. The thighs are armed with a few, and the tibiæ with many, small sharp spines.

3.—Leg of Cockroach.

The first ring or segment of the chest is on the upper surface (or back) expanded into a broad plate overlapping the head, and forming the *pronotum*. In the young cockroach and in the female adult, the next two rings are also visible from above, but in the male when the wings are closed they are not visible. If we raise the wings of the male, we will be able to see that the first pair is attached to the side of the second ring, and the second pair to the edge of the third ring. The front wings (or as they are termed in the Orthoptera, the *tegmina*) are brown and much stiffer and more horny than the thin hind wings, which are moreover folded longitudinally. Both pairs are strengthened by thicker veins or nervures. In the male the wings do not reach to the end of the abdomen, and it is probable that in this species they never serve as organs of flight. In the female the front wings are very small, and the hind pair seem to be altogether absent, but at the place on the third ring of the chest where they ought to be, are triangular wrinkled marks which probably represent them.

The abdomen or hind body is, like the thorax, composed of rings or segments, the number of which appears to differ in the sexes, and also according as the upper (dorsal) or under (ventral) surface is looked at. In the male, nine segments are visible above and eight below; in the female eight can be seen above and seven below; but in both sexes there is reason to believe that there are in reality eleven above, though some are much concealed, and others altered in form. To each side of the tenth dorsal segment is attached a short spindle-shaped appendage, consisting of many joints and called the *cercus*. It is probably an organ of touch, but its exact use is unknown. In the male the ninth ventral segment is provided on each side with a short unjointed appendage called a style. The structure of the apex of the abdomen varies according to the sex.

The fact of the domestic cockroach being so common an insect, and of a convenient size, has led to its internal structure having been frequently investigated. Like other insects, and their allies, the skeleton or framework to which the muscles are attached is external, and consists of the horny material called chitine. There is no proper internal skeleton, but there are processes or projections on the inside of the chitinous integuments, or external skeleton, sometimes reaching from side to side, which supply the place of an internal framework.

The *alimentary canal* (Fig. 4), which is almost twice as long as the body, begins at the mouth, which, as already described, is furnished externally with a complex arrangement of jaws and palpi. In the middle of the mouth is the tongue, attached to the inner side of the labium, in front of the gullet (*g*). The latter, after passing through the neck and thorax, gradually widens out into a large crop (*c*), which is followed by the pear-shaped gizzard (*gi*). This organ (the gizzard) has very muscular walls, the inside of which is provided with strong teeth. These teeth, which are formed of chitine—the horny material already mentioned as forming the external skeleton, and which also lines the inside of the

alimentary canal from the mouth to the gizzard—are arranged thus:—Six large ridge-like teeth, with five smaller ridges between each pair and still finer ridges between these again. Behind the teeth (*i.e.*, towards the narrow end of the gizzard) are six

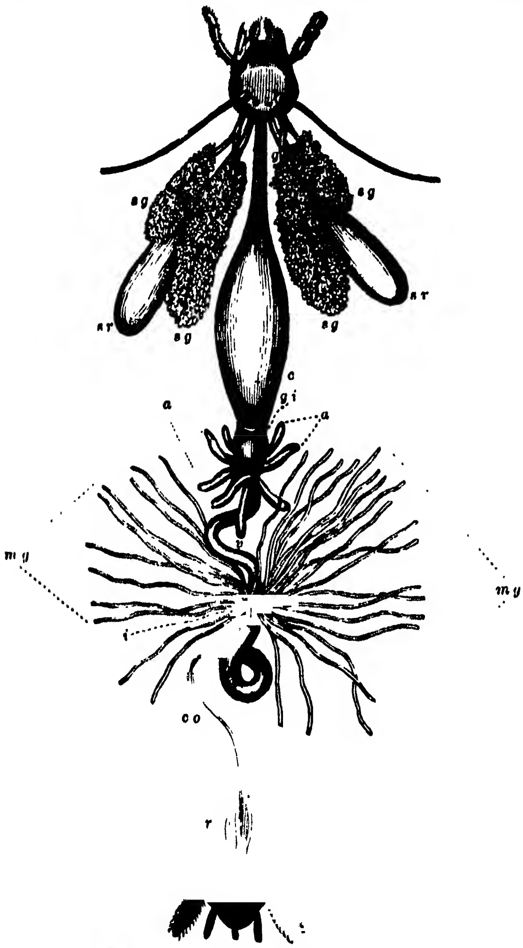


Fig. 4.—Alimentary Canal of Cockroach.

cushions set with fine bristles. The gizzard opens into another wide tube—the *ventriculus* (*v*)—into which also open seven or eight smaller tubes (*a*), of various lengths, and closed at one end. The ventriculus joins the intestine proper, consisting of first, a narrow tube, the *ileum* (*i*); second, a wider tube, the *colon* (*co*); and third, a short straight canal, the *rectum* (*r*). At the place where the ventriculus joins the intestine, a considerable number of slender tubes—the *Malpighian glands* (*mg*)—closed at one end, open into it. In addition to these structures the alimentary canal is provided with two *salivary glands* (*sg*). These lie on each side of the gullet and crop, and are about one-fourth of an inch long. Rather behind the salivary glands lie the *salivary receptacles* (*sr*), two in number, and which may be compared to a bag with a long tube-like mouth. These tubes join the tubes which come from the salivary gland; and all of them unite into one (the *salivary duct*) which opens into the mouth underneath the tongue.

As in other insects, the *blood circulatory system* is not very complex. The representative of the *heart* of more highly organised animals is a slender tube lying in the middle line of the back of the abdomen and communicating with the thorax and head by a fine canal. Along each side there are a series of openings, but with the exception of the canal in front, there seem to be no vessels (*i.e.*, veins and arteries) given off by the heart. The blood, which is a clear, cold, almost colourless fluid, is driven through the body by the pulsations of the heart, finding its way in the spaces between the various organs, and bathing the latter.

The breathing *system* is similar to that of other insects.* On each side of the body are ten openings (two in the chest, and eight in the abdomen) called *spiracles* or *stigmata*. Those in the chest will be found situated between the segments or rings which form it: the abdominal ones are rather concealed, but may be seen by taking a recently-killed cockroach and pulling the abdomen gently so as to slightly separate the segments. The spiracles can then be seen at the angle formed at the back of each segment by the junction of the upper and under surfaces, and look like the ends of fine tubes pointing backwards. Within each is a valve by which it can be opened or closed. The spiracles are connected with slender branching air-tubes or *tracheæ*, which ramify through the body of the insect. These tubes are composed of two (or in the larger branches three) membranes, between which a thread-like fibre runs spirally round the tube and strengthens it. Immediately after leaving the spiracles, the tracheæ divide into two, one branch going to the upper (dorsal) side, the other to the lower (ventral) side of the body. The dorsal branches join in a series of arches on each side of the heart, while the ventral ones are connected by longitudinal trunks. Their finer branches supply the other internal organs, viscera, nerves and muscles. The wings also, when they are present, have a supply of tracheæ running along the nervures. The head and its organs are supplied from the spiracles that

* "Science for All," Vol. I., p. 109; Vol. III., p. 66.

open between the first and second segments of the thorax.

As in other insects, the *nervous system* consists of a series of ganglia (masses, or as it were depôts, of nerve material) connected by nerve-cords. Of these ganglia two are in the head, one (the so-called brain) above, and the other below the gullet; each of the three segments of the thorax has a large pair, and there are six smaller pairs in the abdomen. The two ganglia forming each pair (both in the thorax and in the abdomen) are coalesced or closely united, and each pair is joined to the following by two stout cords. This thoracic and abdominal series of ganglia is situated along the under side of the animal, and not on the dorsal or upper side, an arrangement contrary to what occurs in the higher or vertebrate animals, where the chief nervous system lies along the back. All the ganglia give off smaller nerves which go to different parts of the body. Thus the one below the gullet supplies the parts of the mouth; the thoracic ganglia supply the thorax and its appendages, *i.e.*, the legs and wings; and the abdominal ganglia supply the muscles, &c., of the abdomen. The ganglion which is situated in the head above the gullet is connected with the antennæ and eyes, and is in addition joined to another set of nerves, also provided with small ganglia which supply the gullet, crop, and gizzard.

Perhaps, among the specimens we have secured, there may be one which by its shortened wings and other features, we now know to be a female, but which has apparently attached to the extremity of its body a large oblong object, nearly half as long as the abdomen. Examining this object we will find that it is oblong-obtuse in shape, one edge being very convex, and the other furnished with an acute saw-like toothed margin. The sides are convex, and each is marked with eight transverse impressions. In colour it is at first whitish, but afterwards becomes brown. This is the egg capsule, and it presents a point of peculiar interest in the natural history of the cockroach, unlike anything known to occur amongst other insects, which usually deposit their eggs one by one, and never in a common receptacle; some members of the order Orthoptera, however, lay their eggs in masses, though not in a capsule. A still more interesting fact has been discovered in the life history of an Indian cockroach, which not only does not produce a capsule, but is viviparous, *i.e.*, the eggs are not laid but are hatched within the body of the parent insect, and are then brought forth. This phenomenon occurs in some other insects, but is rare.

In texture the capsule is horny, and along the acute margin is a slit with saw-like edges, the teeth of one edge fitting tightly into the teeth of the other, and moreover strengthened with a kind of cement. If we detach the capsule and cut it open we will find that it is divided into two spaces, each containing a row of chambers, and in each chamber a single egg. The external transverse impressions indicate the number of chambers, which in the capsule of the common domestic cockroach are sixteen. The capsules of other kinds of cockroaches have a different number, some having as many as thirty. The animal takes some time—even so long as a week—in giving birth to the capsule, and then selecting a safe place for its deposition, secures it there by a glutinous secretion.

The eggs are cylindrical in form, and being protected by the capsule have thinner and more transparent integuments than is generally the case in insects. Hence they are well adapted for studying the development of the embryo.

When the eggs hatch the young cockroaches discharge from their mouths a fluid, which softens the cement that closes the slit, which they are then able to push open and make their escape, the slit closing again behind them.

When newly hatched the young animals are white and somewhat transparent, but after a short time become darker. As has been already mentioned, there is at first no vestige of wings, which are peculiar to the perfect condition. In most other respects they resemble their parents, except in being paler in colour and of course much smaller. But they soon begin to grow, and as their skins do not grow with them, they are obliged to change them or moult. How often the change of skin takes place in the common house cockroach is somewhat uncertain. One observer says that it moults seven times, the first moult taking place as soon as the insect is hatched, the second at the end of a month, and the remaining five at intervals of one year, so that the perfect condition is not attained till the insect is five years old. According to observations made by another naturalist on another species there are six moults, and the insect becomes adult in from four to six months from the time that the eggs are hatched. In moulting, the horny skin splits along the middle line of the back of the head, thorax, and abdomen, and the insect emerges, from the opening thus made, clad in a new skin which, at first soft, soon hardens.

There does not appear to be, in the common cockroach, any particular time for egg-laying, as

the insects of all ages may be found at any time. Only one capsule at a time is produced by a female cockroach, but how many it can produce in its lifetime is uncertain, as is, in fact, the length of the duration of life. Though from the very first the young ones have a tolerably close resemblance to their parents, this resemblance increases with each change of the skin, and is more especially visible in the gradual development of the segments of the thorax. It has also been noticed that if the antennæ are cut off near the base in the very young cockroach, they will be reproduced to a certain extent at the next moult—a fact which, though not peculiar to this insect, is yet of considerable interest.

It is said that the march of empire is westerly, and this seems as true of cockroaches as of men. Our common domestic cockroach, though now so widely distributed, is not an aboriginal native of this country, but an invader who "came in" at no very distant date. When it first made a landing is uncertain, but it is only about ninety years since Gilbert White recorded its first arrival at Selborne, only fifty miles from London; and it was not till about 1735 that it reached Sweden. It is supposed to have been originally a native of India, and to have reached us in ships from Asia Minor, but as it is now so widely spread all over the world, it is difficult to determine what country has the invidious distinction of having given birth to *Blatta*, or *Periplaneta*, *orientalis*. *Blatta*, it may be remarked, is an old classical name, applied by the ancients to some unknown kind of insect, but now used by modern naturalists to denote a genus of cockroaches. *Periplaneta*, the more correct *generic* name of the insect under discussion, is derived from the Greek word *periplanaomai*, and was given in allusion to the facility with which the cockroach has wandered all over the world, while *orientalis*, which is the *specific* name, indicates the supposed or real eastern origin of the species.

Wherever it came from, *P. orientalis* is a true Anglo-Saxon in its capacity for colonisation. In Britain it has established itself all over the length and breadth of the land, but is chiefly, if not altogether, confined to houses, inhabiting kitchens, sculleries, bake-houses, and such-like places, where plenty of food can be obtained. Nothing that is eatable (and many things that are not usually considered edible) comes amiss to this voracious animal, than whom it would be difficult to find a more omnivorous creature. In addition to almost every article of human food, such apparently unpalatable objects as woollen garments, the greasy rags used in cleaning steam-engines and other machinery, shoes and other articles of leather, and even books and paper enter into its bill of fare. In warehouses and on board ships the ravages it commits are great, whole barrels and sacks of flour, corn, rice, and other articles of a like nature being sometimes consumed by it. Amongst other things cinnamon is said to possess great attractions for the cockroach palate, and there is a scandal to the effect that those whose business it is to reduce the cinnamon sticks to powder are not very careful to separate the spice from the insects—which sometimes constitute nearly half the contents of the bags—but tumble them altogether into the mill.

Though to its other crimes the cockroach does not apparently add that of cannibalism, the cast skins and the interior of the egg-capsules are said to be eaten by them, and other insects are occasionally devoured. Amongst the latter is said to be the common bed-bug, which, if true, is a point in favour of the cockroach.

In habits *P. orientalis* is strictly nocturnal. During the day it hides in crevices in the floor, behind the wainscot, or in any other dark hole, where it lurks till the darkness and quiet of night tempt it forth. It seems to be fond of warmth, as it is always found in greater abundance near fireplaces and ovens. Though this or some allied species of cockroach was well known to the ancients, and termed by them *Lucifugæ* because they ran away from the light, it is not quite certain that it is not the sound of the footsteps of the person carrying the light rather than the light itself which alarms them.

They run with great celerity; but, though quite able to ascend perpendicular surfaces, they do not, as a rule, when established in the kitchen, venture up-stairs. Probably, the larger supply of food and greater warmth tend to prevent them from wandering from the kitchen and its adjuncts. When seized they discharge from their mouths a brownish fluid of most disgusting and persistent odour, which, moreover, clings to any objects over which they have crept. This, in addition to their voracity, makes them most undesirable inmates of a house.

Bad as our domestic cockroach is, its ravages are trivial in comparison with those of some of the tropical species. For example, in the West Indies the giant cockroach (*B. gigantea*), a species many times the size of *Periplaneta orientalis*, must be an

intolerable nuisance. It sometimes swarms in old houses to an incredible extent, devouring almost everything and defiling what it cannot devour. It is said even to attack sleeping persons, and gnaw the ends of their fingers and toes; and, such being the case, it may be imagined that it does not spare the dead. In addition to all this, it is able to make a noise like a sharp tap on wood, whence it has been called the "drummer," and this tapping it keeps up throughout the night.

Periplaneta orientalis is not the only cockroach that we have in Britain. There are at least two other introduced species, besides several indigenous ones. The latter are mostly small insects which live out of doors, on the sea-shores or in woods and on heaths, and are not strictly nocturnal in their habits.

Of the introduced species, the first place may be assigned to *Periplaneta americana* (Fig. 5), which, introduced with sugar, &c., in ships, from the warmer parts of America, has now established itself in several parts of Europe, some of them far inland. It is not generally, though occasionally, found in houses, but sometimes swarms in ships, docks, and hot-houses. In the latter it probably does damage to the plants, and especially to orchids, inside the pseudo-bulbs of which it, in company with five other kinds of cockroach, has been found. (Another cockroach—*Blatta melanocephala*—has also been found injurious to orchids in this country.) *P. americana* is bigger than *P. orientalis*, and in both sexes the wings, both front and hind, are well developed, so that it can fly. Like *P. orientalis*, it is nocturnal in its habits.

Another probably introduced species is *Blatta germanica*, a considerably smaller insect and a native of Europe. Its distribution in this country is uncertain, but it has been taken in London and its neighbourhood. Unlike the common domestic species, it is not entirely nocturnal in its habits, but comes out in the day-time, running up the walls and over the tables, as well as flying about. Neither is it entirely confined to houses, as it more properly lives in woods, but, like other cockroaches, it has a great power of adapting itself to circumstances, and, when once established in a house, makes itself quite at home. It has been noticed that in some places *B. germanica* has been driven out by the larger *P. orientalis*, but in others the reverse has happened. There is still another species which has been introduced with merchandise into London and elsewhere—viz., *Panchlora maderæ*, a native of the island of Madeira; and, very probably, there may be others which have gained a local footing here and there.

In Lapland, one of our small native species, which in this country does not appear to come into houses, occasionally swarms in the huts of the Laplanders, and does great damage to their winter store of dried and salted fish.

As a family, the cockroaches have an immense antiquity. Though neither they nor any other insects have yet been found in the oldest fossiliferous strata, they make their appearance in the palæozoic or primary rocks, numerous remains having been discovered in the coal measures of the Carboniferous period. In fact, judging from the abundance of the remains of cockroaches as compared with those of other insects, the family had probably even then a great antiquity. Of course, these ancient cockroaches are not identical with those of the present day; but, considering the immense (and by us unappreciable) period of time that stretches between then and now, they are wonderfully alike, and were even then highly specialised.

In addition to man, cockroaches have other natural enemies. Notwithstanding their bad odour, hedgehogs, ducks, and some monkeys, will eat them, and the first-mentioned animal is sometimes kept in houses on purpose to devour them. But besides these, they have their own peculiar foes. Amongst these there is a curious beetle—*Symbius blattarum*—which is parasitic in the bodies of *P. americana* and *B. germanica*, while several ichneumon flies are parasitic either upon the insects themselves or upon their eggs. Another fly—allied to the wasps—in warmer countries provisions its nest with cockroaches, stinging them so far as to paralyse them, but not to kill them outright. Our common domestic cockroach is also infested by parasites of a much lower type, such as *Gregarina blattarum*, and at least five or six other animals which live in the intestines. Finally, the common house-cricket—itself a destructive pest—is said to attack and eat the common cockroach; but this has been denied.

A word or two on the best means of ridding houses of cockroaches—deduced from the scientific facts mentioned—may fitly conclude this paper. An old and serviceable method is to use a small box in the lid of which is a round hole fitted with a glass rim, which, while permitting the entrance of the insects, prevents their escape. Some attractive bait is put into the box, and in the morning the captives can be destroyed. A more effectual mode of destruction is the use of powdered borax

sprinkled in their haunts. The efficacy of this is vouched for by one of our foremost entomologists, who declares that he made his kitchen free of cockroaches by the use of borax daily for two or three weeks. Another way, also highly praised, is the use of an insect powder which consists of the powdered flower-heads of *Pyrethrum roseum* and other species of *Pyrethrum*. This powder, sprinkled in their hiding-places, is said to speedily give a "happy despatch" to the "black beetles."

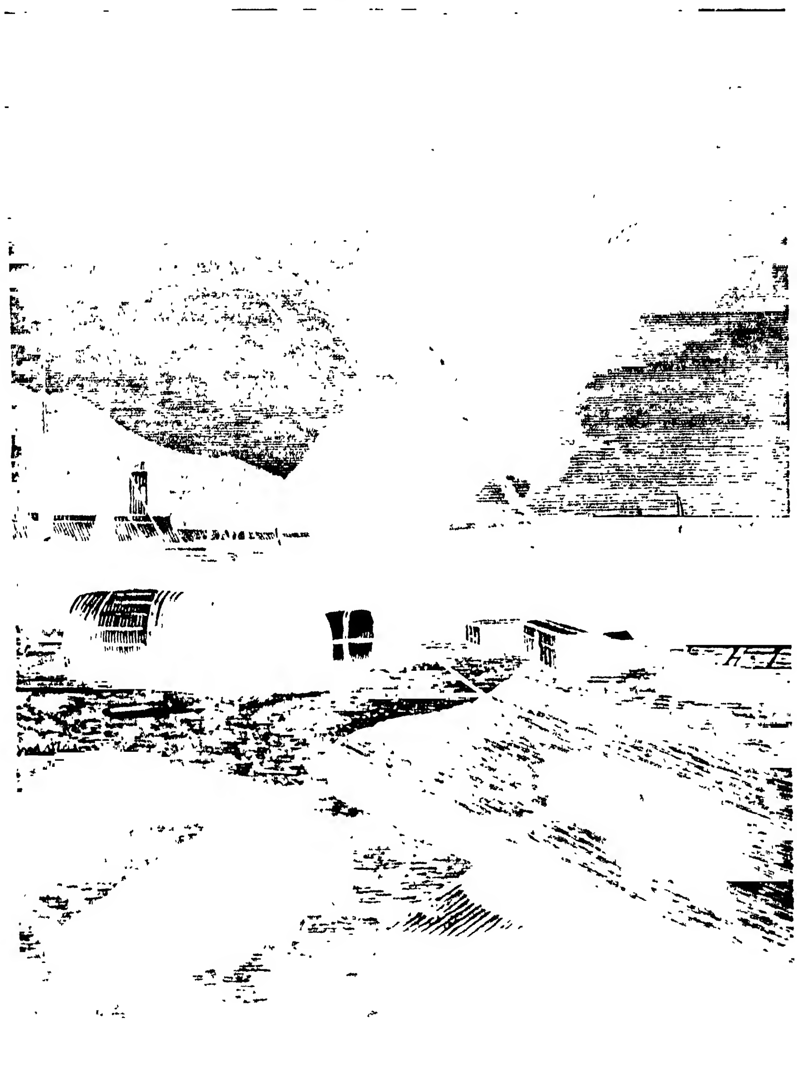


Fig. 5.—PERIPLANETA (BLATTA) AMERICANA.

HOW ELECTRICITY IS GENERATED IN THE AIR.

BY ROBERT JAMES MANN, M.D., F.R.C.S., F.R.A.S., ETC.

IN a former paper describing the general characteristics of thunderstorms,* allusion was made to a previous description of the instrument that is most generally employed for detecting the presence of faint manifestations of electrical excitement.† When, however, it is the free electricity lodged in the air which has to be dealt with, a somewhat important modification of this simple piece of experimental apparatus has to be made. Two light pith balls are used instead of one, and those balls are suspended by fine *metal threads*, instead of by fibres of silk, and are caused to hang down into the interior of a bell-shaped cover of glass from the bottom of a copper rod, which is prolonged upwards above the glass cover for about twenty-four inches, and then terminated in a point, as represented in the annexed figure (Fig. 1), in which the apparatus bears the form that is known as De Saussure's electrometer, in reference to the name of the distinguished Genevese professor and traveller, who contrived and first employed the instrument. De Saussure used this apparatus in his early investigation of the conditions of atmospheric electricity nearly a century ago, and it is still often employed for the same purpose on account of its convenience and simplicity, although more sensitive instruments for testing the electrical conditions of the air have since been devised and brought into operation.

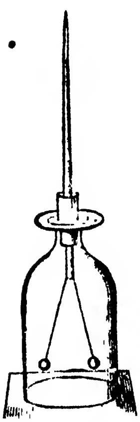


Fig. 1.—De Saussure's Atmospheric Electrometer.

If a piece of sealing-wax which has been briskly rubbed by a dry and well-warmed pad, composed of two or three thicknesses of flannel, be brought into contact with the upper part of the copper rod of this apparatus of De Saussure's,‡ the pith balls suspended within the glass reservoir beneath, immediately become each of them equally charged with the electrical force generated upon the sealing-wax by the friction, and repel each other in consequence of this charge, so that they stand apart, as represented in the figure, instead of hanging closely together as they did before they were influenced by the electric disturbance. If, however, when they are in this repellent state a glass rod which has been briskly rubbed in the same way by a piece of warm dry silk be brought into contact with the copper stem of the apparatus, the divergent balls immediately fall together, in consequence of the electrical state into which they had been thrown by the excited sealing-wax being neutralised and removed by the different electrical state which is called up on glass when it is in its turn subjected to friction. It must here, therefore, be marked and remembered as a great fundamental axiom in electrical science, that there are two distinct and opposite states of electrical activity, of which one is called the *resinous* electrical state, because it is manifested when sealing-wax or resin is rubbed, and of which the other is called the *vitreous* electrical state, because it becomes manifest when a vitreous substance, like a glass rod, is subjected to the same treatment. It has been found convenient to speak of these different states as if they were produced by the presence and operation of distinct and antagonistic agents, which are both distinguished as electricities.§ The alternative phrase of "opposite electrical conditions," which is also very commonly employed, is, no doubt, in some sense more satisfactory. But in regard to any of these modes of expression it must be kept carefully in mind that in dealing with matters of this class science continually employs terms and language which enable a familiar conception of the whereabouts of truth to be formed through an arbitrary assumption. As a matter of fact no one yet knows what the agency termed electricity actually is. But it is nevertheless found convenient to speak of that unknown agency under a definite name, on account of the opportunity which this affords of a short cut to an intelligible explanation of modes of action—of ways and means—which could only be otherwise reached by a round-about progress through a devious and more perplexing route. The two electricities are, therefore, in this place to be accepted merely as a convenient fiction of science, which may be advantageously employed to simplify the description of results. It is the effects which can be observed,

* "Science for All," Vol. I., p. 263.
† "Science for All," Vol. I., p. 45.
‡ "Science for All," Vol. I., p. 45.

§ The resinous electrical state is also spoken of as negative, and the vitreous state as positive, in reference to the notion of Franklin that in the one condition the so-called imponderable agent which in his time philosophers conceived electricity to be was wanting, or absent; and that in the other case it was largely accumulated, or redundant.

nevertheless, and not the assumed agency, that constitute the circumstances that have to be dealt with by the understanding of the reader.*

The familiar conception of electrical agency is based upon the assumption that all bodies in the natural and undisturbed state contain within themselves two distinct kinds of electricity which saturate and neutralise each other when they are combined together in proper amount, and then manifest none of the active characters of the electric state, but which both become active and demonstrative as electrical force when this close union is disturbed, and the two kinds are severed from each other. The French electrician Du Fay first noticed the existence of the two distinct kinds of force. He discovered their difference in this simple way. He observed that a small fragment of gold-leaf floating in the air was attracted by a glass tube which had been rubbed by silk, and that it was immediately repelled by the glass rod after it had once touched its surface, and so acquired its own proper electrical state by the contact. But he also remarked that a rubbed stick of sealing-wax attracted the gold-leaf which was at the time repelled by the glass. He hence instantaneously inferred that it is one of the essential attributes of the two distinct kinds of electricity to enable bodies that are charged with the same kind to repel each other, and to cause bodies that are charged with different kinds to attract each other. The repulsion of the pith balls of De Saussure's electrometer when its rod is touched with excited glass is due to this circumstance: they repel each other because they share equally between them the charge which is communicated to the instrument from the excited glass.

The discovery that some bodies readily transmit charges of electricity along their own substance, and that others prevent or impede their passage, was made in 1729 by Stephen Gray in the manner described in a previous article.†

Pack-thread and wire hence came to be called conductors of electricity, and silk to be considered as an impediment to transmission, or, in other words, an insulator and imprisoner of any electrical charge. Metals, charcoal, and moist substances, including the bodies of living vegetables and animals, were all found to be conductors of the electric charge, some more and some less. Silk, india-rubber, glass, sulphur, wax, resin, and dry paper, on the other hand were all ascertained to be insulators, or impediments to the transmission of the charge. This discovery of the conducting and insulating powers of different kinds of bodies was a circumstance of the utmost moment, because it was through its instrumentality alone that it became possible to accumulate and confine charges of electrical force, so that they could be made the objects of investigation and experiment.

The pith ball electrometer contrived and adopted in his researches by De Saussure is quite competent to afford a ready indication of the presence of an electrical charge, and it is also capable by the alternate use of excited rods of glass and sealing-wax of indicating the kind of electricity which is concerned in producing divergence in its balls.‡ There is, however, another form of electrometer, which is now regarded with even greater favour than De Saussure's on account of its superior convenience and sensitiveness. In this strips of gold-leaf are substituted for the balls of pith. This form of instrument was invented by an electrician named Bennet, and is therefore known as as Bennet's gold-leaf electrometer (Fig. 2). The strips of gold-leaf are so light, and at the same time of such high conducting power, that they fly boldly asunder under the most trifling disturbance of the electrical equilibrium. When this form of instrument is used for examining the electrical condition of the air, the copper rod carrying the strips of gold-leaf is terminated above by a clip instead of by a point, so that a small piece of sponge saturated with spirit of wine may be fixed in it. The spirit is then set light to whenever any observation is to be made, and it is found that the flame in such

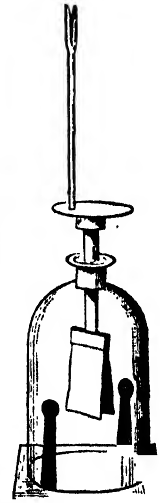


Fig. 2.—Bennet's Gold-leaf Electrometer, with the Strips of Gold-leaf diverging from each other under an Electrical Charge.

* What in familiar language are called opposite electricities are almost certainly opposite molecular conditions of material substance. But the familiar language, rather than the improved and advanced phraseology, is designedly used in these pages, because it is scarcely possible within the narrow limits of a popular article to make plain all that has to be told regarding the nature of atmospheric electricity, without the help of this device.

† "Science for All," Vol. III., p. 53.

‡ The terms "positive" and "negative" will henceforth be used in the following explanations, without the synonymous appellations of "vitreous" and "resinous," as the distinctive designations of the two different kinds of electrical state. But the reader is requested to bear in mind that those terms are employed simply as convenient distinctions sanctioned by very general adoption, and not in any sense as implying the acceptance of the theory of Franklin with which they were in the first instance associated.

circumstances gathers in the charge of electricity from the air much more readily than any form of point would do.

It will be thus understood that there are two cardinal facts which it is necessary to keep prominently in mind when entering upon the consideration of atmospheric electricity from the meteorologist's point of view. First, the existence of two quite distinct electrical states, which are capable of manifesting themselves by the familiar effects of attractions and repulsions; and secondly, the two opposite properties of insulation and transmission which different classes of material substance exhibit for these states. Having premised thus much, it now becomes necessary to trace one other result which follows naturally as a consequence of these conditions. This consequence of the relation of the two electrical states to insulating and conducting substances has been incidentally touched upon in a previous paper on "Thunderstorms,"* but in order that the meteorological conditions of thunder and lightning may be fully understood, it has been found necessary to amplify somewhat the elementary details there given.

There is, perhaps, no doctrine of physical science which is less generally comprehended than the one which is comprised in electrical induction. The principle involved is, nevertheless, more or less operative in all electrical phenomena, and it is hardly too much to say that there can be no adequate grasp of the meaning of such phenomena without its aid. At the first glance this matter bears, for the uninitiated, a very complicated and perplexing look; but fortunately it is by no means so formidable as it appears when it is approached through the easy road of direct experiment, which indeed was the method that was in the first instance

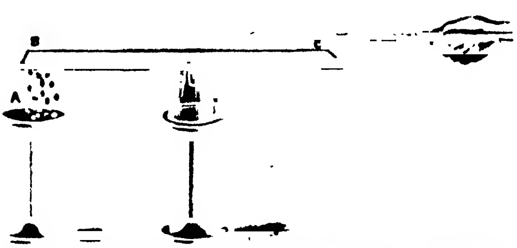


Fig. 3.—Experiment to illustrate Stephen Gray's Discovery of Electrical Induction.

pursued at the time of its original discovery by Stephen Gray. This ingenious experimenter placed a flat lath of wood upon an inverted tumbler, as represented in Fig. 3, and then scattered a few fragments of gold-leaf upon a stand (A) three or four inches beneath one end (B) of the lath. Having made this arrangement of his rude apparatus, he rubbed a glass rod briskly until it was in an electrically excited state, and then held the glass rod over the opposite end (C) of the lath a short distance away, as shown in the figure. The small fragments of gold-leaf began immediately to dance up and down between the lath and the stand, as represented in the figure, under the influence of the electrical force, which had been produced in some mysterious way at this end of the lath *by the mere influence* of the presence of the electrified glass rod near the opposite end. Whenever the glass rod was taken away the fragments of gold leaf fell to the stand, and all manifestations of electrical action ceased. But the instant the glass rod was again brought near to the lath the fragments resumed their excited dance. This is a very complete illustration of the case of electrical excitement by mere influence, or *induction.*† There is in this experiment no communication of any electrical charge from the glass. Nothing in reality passes between the glass and the lath excepting an influence. The lath is sympathetically electrified by the mere close neighbourhood of the excited glass rod. The scientific explanation of this very beautiful and instructive experiment of the old Charter House pensioner is to the effect that in its natural state, and before the excited glass rod was brought near to it, the lath contained an equal amount of both kinds of electricity, the positive and the negative, which were for the time naturally combined together, or in a mutually saturated state, and on that account inoperative as an effective force. But when the excited glass rod is held over the end (C) of the lath, the two previously combined, and therefore quiescent, electricities are separated from each other by its inductive influence, and all the negative electricity is drawn toward the end (C), whilst all the positive kind is driven to the opposite end (B). But the free positive electricity (at B) then acts upon the fragments of gold-leaf, also inductively, first drawing them into contact, and then having communicated a positive charge to them by contact, repelling them from the lath until they have discharged that communicated electricity into the stand (A), and are so competent to be once again drawn back to the lath. When the excited glass rod is withdrawn from the neighbourhood of the lath (at C) the severed positive and negative electricities rush back to mingle with each

* "S[illegible] for All," V[illegible]

† Induction, from the Latin word *induco*, to lead in.

other again in neutralising union, and all electric manifestation disappears. But they are then, of course, in a state to be driven asunder again whenever the excited glass rod is once more brought near, and this process of tearing asunder and recombination can be repeated any number of times. Such is an explanation in its simplest form of the phenomena of electrical induction, in which an active electrical state is produced by the mere decomposition and sundering of the electricities present in an insulated body, without the superaddition of any actual charge by communication from without. It is a mere disturbance of the natural state of electrical repose through the influence of the near neighbourhood of an excited body, which manifests itself by the accumulation of the one kind of electricity at one end of the disturbed body, and of the other kind at the opposite end. The sympathetic disturbance continues as long as the exciting influence is near, but ceases the instant that influence is removed. One crucial test of an electrical state being a result of inductive disturbance, and not of a communicated charge, is found in the fact that in such circumstances there are always the opposite kinds of electricities producing their characteristic attractions and repulsions at opposite parts of the disturbed body. An inductively electrified body always has two opposite poles of positive and negative action. But an insulated body which has become the seat of a communicated charge manifests the same kind of electricity, and that kind only, throughout its entire extent; it has no electrical polarity.

Another important peculiarity incident to the electricity produced by induction, which must on no account be overlooked in considering the effects of atmospheric disturbance, is that an induced state of excitement may at any time be converted into an actual charge of a force of one kind, by a very slight change in the conditions by which the decomposition is temporarily brought about. In the experiment with the inductively excited lath, if, when the excited glass rod is held over one end, and the fragments of gold-leaf are dancing up and down beneath the opposite one, that end of the lath be touched for an instant by the experimenter's finger, all manifestation of the electrical excitement disappears. But when the glass rod is withdrawn from the neighbourhood of the lath, the excitement immediately reappears, and is of an *opposite kind* to that which was in the first instance set up at the gold-leaf end by induction. The fragments of gold-leaf begin again to dance; but it is under the impulse which belongs to the *negative* state, instead of under that of the positive state, which was in the first instance brought about at that end of the lath by the induction. The explanation of this is that when the lath was touched by the finger, all the positive electricity accumulated at that end escaped. But when the finger and the glass rod were withdrawn the electricity concentrated at the opposite end rushed back along the lath, and as there was not then a due amount of the positive electricity remaining in the lath for its neutralisation it remained in the ascendant, and the whole lath became charged with an active negative state which was able to set up attractions and repulsions on its own account. A very simple and most easily-constructed piece of apparatus may be arranged so as to enable any one to trace these curious effects of inductive action by direct observation and experiment. It is only necessary to place two balls of wood, A B, covered with either tin-foil or gold-leaf, in wine-glasses, and to connect the balls together by a piece of brass chain, C, as represented in Fig. 4. It will

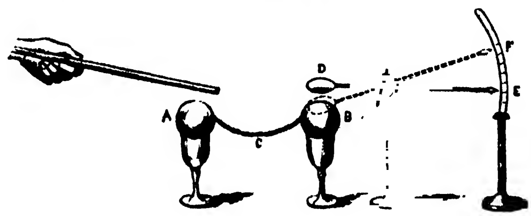


Fig. 4.—Experiment to illustrate the Nature of Electrical Induction.

then be found that if a glass rod be briskly rubbed with a silk handkerchief, and held a little distance above the ball, A, the electrical equanimity of the system of the chain-connected balls will be inductively disturbed, and the positive part belonging to A will be driven into B, whilst the negative electricity of B is simultaneously drawn into A, so that a balanced straw resting upon a needle thrust transversely through it, and carrying a round disc of metal foil at one end, and placed as indicated at D, would immediately manifest the presence of electrical excitement by the disc being drawn into contact with the ball, and the further end of the straw being tilted up in the opposite direction (from E to F). As often as the glass rod is brought near to A this effect will be produced, and as often as the glass rod is removed from the vicinity of A the effect will cease. In making this interesting experiment, which is, in reality, of very easy

performance, it is simply necessary to take care that all the glass part of the apparatus is in the first instance warmed and thoroughly dried before a fire, as otherwise the separated electricities may be discharged to the earth along the moist surfaces instead of being imprisoned and retained to manifest themselves by the means which have been described. If the balls, A, B, are tested when the induction is set up by the excited glass rod, it will be found that A is in a negative, and B in a positive, state. But if B is then touched for an instant by the experimenter's finger, and the glass rod removed, both A and B will remain *charged* with one kind of electricity—the preponderant residuum, namely, of the negative electricity left diffused through the chain-connected system of balls.

The French electrician, Du Fay, contrived a very amusing and effective plan for showing this curious result. He suspended a board by four strong ropes of silk, and then placed a boy, stretched on his back, upon the board, as shown in Fig. 5. Whenever in

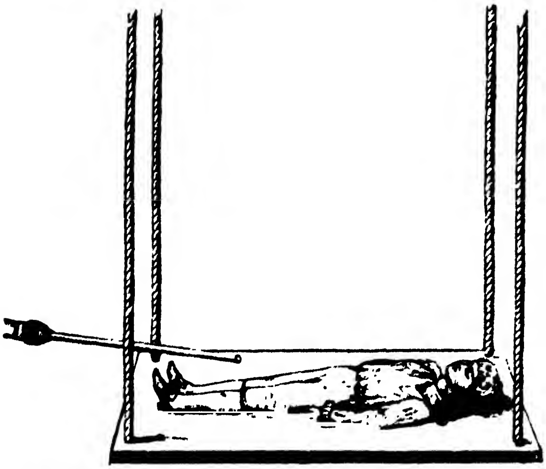


Fig. 5.—Du Fay's Experiment to show the Effects of Electrical Induction in the Body of a Boy insulated by Silk Cords.

these circumstances an excited glass rod was held over the feet, the head immediately manifested the same kind of electrical force as the glass rod, and produced the appropriate attractions and repulsions upon light bodies brought near. If, for instance, with such an arrangement, the straw indicator (D E, Fig. 4) were placed so that the disc of metal foil was just above the tip of the boy's nose, it would be seen to be drawn down to the nose whenever the excited glass rod was held over the feet.

After a careful consideration of these experiments it will be very easy to understand that the essential distinction between a body carrying an electrical charge and one that is in an inductively disturbed electric state is that in the first case the electric energy pervades the entire substance so far as it is girt about by an imprisoning or insulating sheath, without any manifestation of opposite states, or of distribution into poles, and that the energy is persistently retained until it is discharged to the earth through a conductor; whilst in the other case the insulated body manifests opposite attributes of attraction and repulsion at remote parts of its surface, which are displayed so long as an electrically excited body is in the near neighbourhood, but which disappear the instant the excited body is removed, and which are capable of being recalled into activity, and of being replaced in abeyance, without any communication of an absolute electrical charge, or any production of an actual electrical discharge, any number of times, by the mere bringing near, and carrying away, of the disturber of the electrical equanimity. In the latter case the effect is simply a result of the troubling of the body's own inherent state of normal electrical repose. This distinction has been here dwelt upon with some elaboration of detail. But it will soon appear that this fulness of explanation is not at all more than the subject in hand both deserves and requires. No clear apprehension of the phenomenon of atmospheric electricity can by any possibility be secured unless the great underlying fact of electrical induction has been adequately comprehended and mastered.

The electrometer which is now held in highest repute by scientific meteorologists engaged in the examination of atmospheric electricity, acts through the agency of induction. It was invented by the French electrician, M. Peltier, and is on that account spoken of as Peltier's Induction Electrometer.

The apparatus consists of a large copper ball, 4 inches across, B, placed at the top of a stout vertical copper rod, R, which passes down through an insulating cover of shellac, C, and so finds its way into the interior of a cylindrical case of glass, G, where it ends in a kind of stirrup, or loop, L, as shown in Fig. 6. The stirrup is attached to a horizontal copper bar, A, terminated at each end in a copper knob, and carries projecting into the loop a point, P, upon which a double needle is balanced by means of a conical cup, so that it can traverse freely round in the manner of an ordinary compass-needle when the cup is placed upon the point. The traversing movement, or double needle, consists of two parallel parts ranged one above the other, of

which the upper one, D, is a needle of magnetised iron, whilst the lower one, E, is a piece of copper wire metallically continuous, through contact of the cup and point, with the vertical rod and ball, B. The stirrup and knobbed bar are steadied beneath by an insulating pillar of glass and shellac, S. When the instrument is about to be used, the balanced needle is allowed to swing round, compass-like, upon its point until it ranges itself in the magnetic

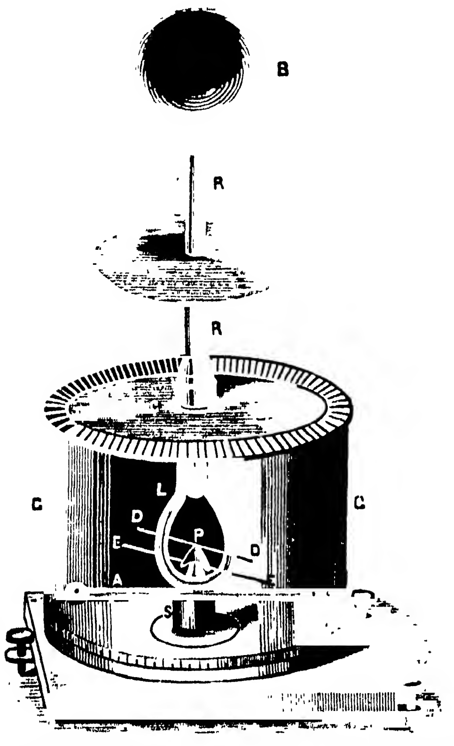


Fig. 6.—Peltier's Induction Electrometer, in which a horizontally-traversing Copper Needle is repelled by a fixed transverse Copper Bar.

meridian of the earth, under the influence of the terrestrial magnetic force. The entire apparatus is then shifted upon its centre until the transverse copper bar, with its terminal knobs, is ranged parallel with the traversing needles. In this state the needles are held in their place by the magnetic attraction, unless the lower copper constituent of the connected pair is more strongly acted upon by electrical repulsion set up in the subjacent knobbed copper bar. This, however, occurs whenever the electrical state of the large copper ball and vertical rod (B and R) is disturbed by electrical induction. If, for instance, an excited glass rod is brought near to the ball (B), the negative electricity of the insulated metallic mass is immediately drawn up into the ball, whilst the positive electricity is driven down into the stirrup and horizontal copper rod, A. But as this horizontal rod, A, and the copper needle, E, are then equally affected by the free positive electricity which has been inductively accumulated at that end—as they share the same accumulation between them—they repel each other, and as the needle, E, by virtue of its suspension upon the point, is free to move, whilst the copper bar, A, is not, the needle, E, traverses round, and departs from parallelism with A as soon as the electrical repulsion set up between A and E is stronger than the magnetic attraction which is exerted between the magnetic poles of the earth and the sympathetically associated pole of the traversing magnet, D. Peltier's Induction Electrometer is thus virtually, it will be observed, an instrument in which the electrical repulsion acts upon a horizontally swinging bar instead of between vertically suspended strips of gold-leaf, or balls of pith, as in the case of Bennet's and De Saussure's electrometers. In consequence of this difference of the arrangement of its parts, and in consequence still more essentially of the force with which the energy of induction can be brought into play, this instrument is more sensitive than either of the older and simpler forms of electrometer; but beyond this it is capable also of measuring the precise amount of repulsive energy which is set up, by means of a graduated arc attached to the circumference of the glass cylinder. This indicates at a glance *how far* the suspended needles D and E have been made to rotate away from the position in which they were parallel with the fixed horizontal bar, A.

When De Saussure had succeeded in the construction of his pith-ball electrometer, towards the end of the last century, he proceeded to put it to practical use by repeating, under the advantages it conferred, some observations which had been previously more rudely made by two other excellent observers—Lemmonier and Beccaria. He at once found that whenever he raised his instrument up a few feet into the air on a clear still day it gave signs of the presence of free electricity, and that the indications of the free electrical force became more pronounced and more energetic the higher the instrument was carried up away from the solid ground into the open and unimpeded air-spaces above. He also noticed that with a clear and serene atmosphere the electrical force so manifested as present in the air was invariably of the positive kind. He likewise succeeded in well establishing

the fact that the presence of this positive electrical force was not shown until the instrument had been raised nearly two yards away from the ground, or above projecting bodies attached to it, such as buildings and trees. The investigations which he thus deliberately carried out, and repeated again and again, soon left the conviction upon his mind that in fine weather the solid surface of the earth, and the immediately superincumbent air are, for some reason, naturally in an opposite electrical state, the ground being negatively, and the air positively charged, and that the neutral, or unexcited, state of the lower regions of the air is due to the continual recombination of the two different kinds of electricity, where they are in close contiguity to each other. M. Becquerel very ingeniously confirmed De Saussure's conclusion of the increase of the free electrical force with ascent into the higher regions of the air by shooting up arrows which carried with them fine metallic threads attached below to the cap of an electrometer. As the arrows rose into the higher regions of the air the pith-balls or the gold-leaf strips of the electrometer became more repulsive and divergent. M. Quetelet found, in observing with the Peltier induction electrometer, which he used upon the lofty tower of the Observatory at Brussels, that the neutral point corresponded with the height to which an iron balustrade extended from the platform of the tower, and that the instrument had to be lifted up some distance above the balustrade before any satisfactory indications of free electricity could be procured.

When the induction-electrometer is employed in this way for delicate observations of atmospheric electricity, a somewhat complicated method of procedure has to be adopted, which is, however, worthy of notice on account of the further practical illustration it affords of the principles of inductive action. The instrument is first raised sufficiently high to furnish signs of electrical disturbance by the swinging round of its suspended needles. The lower part of the vertical copper rod is then touched for an instant by a piece of metallic wire held in the hand. The touch immediately reduces the instrument to equilibrium—that is to say, the traversing needles swing back from the position of disturbance to the position of rest under the magnetic attraction. The instrument is next brought down from its elevated position, and it then appears that it is no longer in equilibrium because the negative state has become preponderant under the change of position from the same influence which has been described in a previous page, where the touching one of the chain-connected insulated balls by the finger after their inductive disturbance was alluded to (p. 337). But the indication of the active electrical state is then of an opposite kind to that which is primarily operative in the air. A negative repulsion of the traversing needles of the electrometer shows that it was a positive influence that was primarily operative in the air. The test of the kind of electrical state which is present in the instrument is, of course, the same with that which is adopted in the case of the simpler forms of instrument. If the bringing of an excited glass rod towards the ball increases the swing of the traversing needles, that shows that it is a positive electrical state which was previously acting upon them. But if it be the approach of an excited stick of sealing-wax which increases the swing, the electrical state of the apparatus was primarily of a negative kind.

Now what are the broad facts ascertained by the close scientific questioning thus carried out through the intervention of these ingenious instruments of De Saussure, Bennet, and Peltier? It is that in fine and still weather the solid surface of the ground, and the air resting above it are in opposite and antagonistic electrical conditions, the ground being in a negative and the air in a positive state.

But when this cardinal fact has once been made out, a further question of the most pressing interest immediately presents itself as a necessary suggestion arising out of the discovery. The insatiable inquisition of science then proceeds to ask what is the primary source of the electrical disturbance which is thus manifested by the positive activity of the air? In his earliest attempt to deal with this question M. Peltier assumed that induction was at the bottom of the matter. He conceived that the void realms of space were naturally and normally in a state of positive electrical charge, that the air served as a neutral and insulating garment to the earth, and that the surface of the earth was consequently in a negative state from the inductive force exerted upon it by surrounding space. More recent investigations, however, have quite plainly and unmistakably proved that such is by no means the principal agency concerned in the effect, and that the air is the seat of a positive *charge* which streams up into it continuously from beneath. A series of influences most probably conspire in furnishing this stream, and although it is hardly possible yet to indicate all the sources of the

supply, there are, at least, some of these agencies which can be detected in their subtle work, and which may safely be credited with a very material share in the operation.

Wherever a collection of water is resting in a hollow basin upon the surface of the earth, or wherever water is running along in the excavated channels of the ground there is always a decomposition and separation of the electricity inherent in terrestrial substance, which then manifests itself as negative force in the solids of the ground, and as positive force in the liquid water. A French engineer officer, M. Becquerel, demonstrated this in a series of very interesting and successful experiments. He placed plates of porous earthenware in water and in the ground, and then associated delicate instruments with them in such a way that he was able to trace an electrical disturbance set up at the surfaces of contact, where the solids and liquids met. M. de Saussure also experimented in a similar direction, and by his experiments proved that whenever water is caused to evaporate rapidly by being thrown upon earthenware crucibles heated to redness, very energetic streams of positive electricity are generated.

The positive electricity which is set free by these agencies is, as a matter of course, carried up by the vapour which rises into the air. Each little particle bears with it in its ascent its own proper portion of the charge. The vast accumulation of water which rests in the wide basins of the sea thus becomes a perfectly inexhaustible source of supply. So long as there is evaporation from the sea, from the rivers, and from the moist porous ground, there must be a positive electrical charge accumulating in the atmosphere.

But in the case of the evaporation of water from the liquid and moist surfaces of the earth, it is not merely the conversion of water from the liquid into the vaporous state which is concerned in the production of the free electricity. The eminent French philosopher, M. Pouillet, has very convincingly shown that no electricity appears when distilled water is projected upon red-hot platinum crucibles, because no decomposition of the water into its constituent elements in that case takes place. *Chemical* change is therefore concerned in the vaporising part of the operations by which free electricity is generated. The Italian observer, M. Palmieri, who habitually watches the fires of Vesuvius from the slopes of its cone of eruption, finds that the vapours which stream from the crater of this restless volcano are invariably charged with free electricity (Vol. III., p. 55). A dry fog which spread over a large part of Europe in 1783, and which was generally ascribed to a volcanic source, was very powerfully electrical. The production of free electricity by volcanic eruption is, indeed, of such frequent occurrence, that the Swiss electrician, M. de la Rive, in the end ascribed the electrical disturbance manifested at the surface of the earth to the *chemical operations* that are in progress within, where the internal part of the solidified crust of the terrestrial sphere is in contact with the molten and incandescent rock that lies beneath the hardened outer shell. When water finds access through the fissures of the rocks to the heated masses beneath, and is converted into steam, there is certainly an ample development of electrical disturbance.

It may thus very safely be held that chemical operations contribute largely to the electricity of the air. The sun's rays exert a powerful effect of a quasi-chemical character whenever they fall upon ponderable substance, and where this occurs electrical force is, in consequence, set free. Electrical disturbance is invariably produced when contiguous bodies are unequally heated by sunshine. The building up of vegetable structure out of the vapours of the air, and the inorganic constituents of the ground, and their destructive decomposition under the oxidising powers of the air, are chemical processes, and attended by the disturbance of the normal and passive electrical state. Wherever chemical transformation, of whatever kind, is in progress, electrical disturbance assuredly is its companion.

The merely mechanical effect of the friction of the particles of moving air against each other, and against solid bodies that lie in their path, most probably contributes to the electrical charge which is accumulated in the air, and must thus be placed amongst the other sources of electrical disturbance which have been alluded to. Some electricians, indeed, are inclined to attribute no inconsiderable part of the electrical manifestations observed to this secondary and less subtle cause.

The vapours which rise from the sea and the moist ground thus carry up with them into the higher regions of the air, the copious and continually accumulating supplies of electrical force which are primarily derived from the various sources which have been named. It is those accumulating stores which are in the end transformed in the clouds into lightning and thunder.

A PIECE OF PUDDINGSTONE.

By Charles Lapworth, F.G.S., etc., Madras College, St. Andrews.

THE casual visitor to a well-appointed museum, who glances over the varied collection of rock specimens there exhibited, generally arrests his steps for a few minutes to study a little more carefully the strange, rough piece of rock labelled "Puddingstone, or Conglomerate" (Fig. 1). It is not only the quaintness of the title that arrests his attention. There is something unique and even startling in the aspect of the stone itself, which appeals directly and forcibly to his imagination.

Fig. 1.—Block of Puddingstone, or Conglomerate.

From this block of grey rock project large pebbles of pure white quartz, knobs of red felstone, black basalt, chips of slate and schists, all more or less imbedded and partly buried up in a very hard, greyish, and decidedly granular matrix, or binding material. These rounded pebbles project on all sides, and there can be no question that they occur also in the body of the rock itself. The vulgar mind, catching ever at the superficial, notices at once the general resemblance in externals between this rock and the Christmas plum-pudding. These large pebbles stand for the plums, these smaller purple chips for the currants, and these white cubical fragments for the chopped suet or lemon-peel of the national dish.

The pudding itself is easy enough of comprehension. We know whence the ingredients are procured, and all the process of their admixture up to the point when the well-cooked result is placed upon our table. But this strange stone is much more puzzling. If a specimen be broken up before the observer's eyes, he will notice that not only do the pebbles occur right through and through the heart of the stone itself, but that the plane of fracture cuts clean across many of the pebbles themselves, as if they were part and parcel of the mortar which binds them together. It is wonderful to him to see a strange array of pebbles, like those he has hitherto been led by habit to associate with wave-worn shingle beaches, water-worn beds of rivers, and the like, lying cemented together into a solid rock-mass. Nor is his wonder lessened when he is told that whole counties in his native islands are almost floored by rocks of this character, and that on the continent of Europe they range over hundreds of miles of length, and rise into mountain-masses, by whose side Snowdon and Helvellyn, and even Ben Nevis itself, would be dwarfed to insignificant mounds.

One point, however, is quite clear to him. All the larger pebbles in the puddingstone are rounded like those of the shingle of the shores and riversides. This rounding, as he already knows,* has been brought about by the continual rubbing of the stones against each other under the force of the waves and streams. No special training or study is required to enable him to reach the inevitable conclusion that these puddingstone-pebbles are old waterworn stones buried up in a mass of disintegrated material, like the pebbles in a roughly-made pathway of concrete.

So far, all is plain sailing. But when we endeavour to answer his very natural questions—why, on the one hand, certain special pebbles predominate, why, on the other, there is such a variety of stones of different kinds collected together—why some are rounded and some angular—why the matrix is so uniform in colour, and possesses such a wonderful toughness and durability—we are staggered at their difficulty, and the apparent impossibility of forcing from Nature, in any one case, a satisfactory reply.

The rounded pebbles of our puddingstone have already told us, in tones not to be mistaken, that only on the shingly shore or gravelly river bottom is it possible to expect an answer to these questions. The river-bed is buried from sight by the flowing streams. Let us follow the only course open to us and go to the shore.

We naturally choose some rocky shore, with cliffs reached by the high tidal-waves; for there will the rounding of pebbles, and the manufacture of material, such as that of which our puddingstone is composed, be proceeding with the greatest rapidity. From the cliffs the storm-waves often detach large fragments of stone. These fall on the

* "Science for All," Vol. II., p. 336.

hard floor and are rubbed and rounded against each other, becoming smaller and smaller daily, until, eventually, they are worn down to the finest sand. In the shallow bays around lie heaps and sheets of these rounded pebbles, of all shapes and sizes, partly buried in sand and small chips of stone. If by any means we could consolidate this loose material just as it lies, it would form rock almost exactly corresponding to our original puddingstone.

Look carefully at the cliffs and rocks above and around. They are sandstones, grey and red. As might have been expected, the vast majority of the less rounded pebbles lying upon the beach is composed of these red and grey sandstones. The very sand amongst which they lie, and which fills up the interstices between them, is but a very little lighter in colour. Every stage of its formation can be seen in the varying sizes of the pebbles, from rounded marble-like fragments, to the smallest grains. It is clearly nothing more than these same sandstones worn down by the sea-waves into their component grains, with their superficial colouring somewhat worn off and subdued.

Here, then, we have already found the answers to two of our questions. The preponderating pebbles of our puddingstone were probably those of the nearest rock in the neighbourhood where the puddingstone was formed originally, and the composition and peculiar colouring of the matrix was compounded of those of the most prevalent rocks there ground down to sand by the waves.

Examine these accumulations of shingle a little more closely. You notice at a glance that large numbers of the pebbles bear no resemblance whatever to the rock forming the cliffs around. Here are balls of pure quartz in tolerable abundance—there pieces of red porphyries. Yonder lie some dark greenstones and basalt. That is a piece of mica-schist. This is clearly a well-marked granite. And these peculiar stones are abundant here. We may count hundreds in the compass of a few yards.

Take up your hammer and strike some of the sandstone pebbles. It passes right through them with a dull "pouff," and the stones fall away almost into a dust of sand. Now strike the quartz, the greenstone, and the granite. How the hammer rings to the blow! The larger specimens refuse to split; they seem as hard as the iron itself. When, at last, you manage to break one of the smaller stones, it flies into two or three angular fragments, tough as steel and sharp as glass. To reduce one of these quartz boulders into small grains you need scores of blows of your hammer; and, even then, your task will be but very indifferently executed; for these grains will still be much larger than the sand grains formed by the waves, and as irregular in form and jagged upon the edges as at first.

Next, take one of the pieces of sandstone to yonder flat slab of rock, and try to rub it down. In a very few minutes you grind it away into a little cloud of sand. Take similar pieces of the quartz or porphyry, and try to do the same. The task is hopeless—you merely rub a deep groove in your bedded slab. The fragment in your hand is simply polished a little on the surface, and that is all.

Now the sea-water must find precisely the same difficulty in breaking up these hard rocks. Every month it pounds the fragments of sandstone to pieces with the greatest ease, and day by day it rubs them down to grains of sand. But the intractable quartz, basalt, and granite pebbles roll backwards and forwards with the tide; a little more polished, a little more rounded, but otherwise unaltered, month after month, and year after year. They keep their places here, as it were, by sheer force of character; they exist in such abundance because the sea finds such a difficulty in getting rid of them.

But, it may be asked, How did these hard stones get here? They are not present in the cliff. They cannot surely have been flung up from the deep sea. They cannot have been created where they lie. They must have been brought from some distant place or places of origin. Where is that place, and what brought them here?

These are very natural and proper questions, and we must find satisfactory answers to them before we can advance a step farther. But the answers will vary with the locality, and with the material of which these foreign boulders are composed. Let us choose a single locality, and work out our problem for that locality as a general type.

We are standing upon the rock-bound shore of the east of Fife, in Scotland. To our left stretches a long range of grey and brown sandstone cliffs. The shelving shore beneath our feet is a rugged floor of reefs and rock-bars. The hollows between these reefs are filled with heaps of rounded masses of sandstone, associated with pebbles of granite, quartz, porphyry, felstone, and the like. The sandstone comes clearly from the cliffs overhead. The pieces of black trap and greenstone probably come from the trap-dykes that occasionally penetrate these sandstones along the coast line, and are brought here by the waves and rounded on the way.

But the granites, the mica-schists, the porphyries, whence come they? for they are utterly wanting along the Fife coast line.

As I walked to this spot across the fields this morning, I saw many heaps of stones piled carefully here and there for the purpose of mending the roads and the "dykes," or stone walls of the country. The stones are collected from off the surface of the ploughed fields by the farm-labourers. I noticed that in these heaps were many large pieces of the dingy sandstones of the district; but, in addition to those, there was an abundance of lumps of porphyry, metamorphic schists, and even granite—rocks not only foreign to this special locality, but many of them entirely wanting among the rock-groups found within the limits of the county. In the hard, tough clays along the brooksides, and present generally upon the surface of country near, these stranger pebbles abound in great numbers; and as the clay is gradually worn away by the wash of the rain, the stones are left loosely projecting from the surface of the soil; whence they are collected by the labourers, or roll down the slope into the stream-beds.

Here, then, we see the proximate source of these foreign pebbles upon the beach. Some of them must have fallen from the summit of the cliff, as they have been gradually eaten away by the sea; whilst the vast majority have been hurried into the sea by the waters of the little brooks in days of storm or flood.

This result, however, satisfactory as it looks, takes us in reality but a single step nearer the solution of the problem how these foreign stones reached their present position in the shingle. They are there, we find, because they have been washed off the surface of the neighbouring soil. But the grand question is, how came they upon the surface of that land, in a district where, as we have seen, they are actually foreigners and interlopers?

Climbing up to the breezy summit of the cliffs, we get a delightful view over the country to the north and west (Fig. 2). Spreading outwards from our very feet, like a rolling carpet of verdure, lies the broad fertile valley of Strath-eden, green with the budding hedgerows, and the fields of early corn. Beyond rise the broad mounds of the Ochils and Sidlaws, their slopes picked out with farms and woodlands, and their grass-grown points bare to the morning sun. Away in the blue distance rises the long line of the Grampians, spotted with trails and patches of the winter's snow. That misty ridge just caught above the wood top to the north-west is Ben Lawers; that pointed peak in the centre is Ben Vrackie, and that long, mount-like summit due north is Mount Battock, near Aberdeen, more than thirty miles away (Fig. 2).

This lovely view has a special interest for us, for those wooded slopes in the mid-distance are the homes of the felstones and porphyries of the pebble beach below us; and those misty peaks on the sky-line mark the fatherland of the quartzites, the mica-schists, the syenites, and granites, that lie by their side.

By proofs too numerous to be cited here, geologists are able to show that at a certain period, not long prior to the advent of man, this lovely view was wanting. Instead of wearing its flowing mantle of living green, the country was buried beneath a pall of ice, so thick that the deepest valleys were filled from side to side, and the very hills buried from sight and ken. This sheet of ice moved downwards and outwards from the higher grounds, carrying with it, frozen into its substance, all the loose stones lying in its path and, with their aid, grinding up the rocky floor, over which it travelled, into a mass of stiff clay, crushing stones and clay together outwards and onwards over the lower grounds. When the great ice-sheet melted at last, this clay, filled with these stones, covered nearly all the rocky sub-soil from the mountains to the sea—the included stones in any one locality being of necessity an intermixture of fragments of all the harder kinds of rocks over which that special portion of the glacier passed which formed it. In that ice-age, the ice-sheet of our locality came down from the high lands of the Grampians over the Ochils; and the foreign stones now found in our clays and shingle are simply those the ice-sheet picked up upon its way.

Thus, in this far-off time, and in this strange manner, we discover one of the causes of the presence of these harder rocks upon our beach. But there are many others, though none perhaps, so far as this region is concerned, of such prime importance.

Look next across the blue waters of the bay to the right. Those distant headlands far to the north are of porphyry, and beyond them the granites and quartzites reach the shore. The line of the coast runs generally north and south, but the tide-waves come in and the fiercest winds blow from the north-east. On every day of north-east gale, therefore, there must perforce be developed a strong tendency in the united action of the winds and waves to drift the shore pebbles to the

southward, along the coast-line; and in this way, in the course of ages, have possibly reached us many of the hard pebbles from the north.

That wide gap in the shore-line yonder marks the mouth of the Tay—the largest river of Scotland. Its broad catchment-basin is floored by porphyries, quartzites, mica-schists, and all the varieties of the rocks we recognise in our harder pebbles. With every great flood it hurries thousands of these pebbles down into its estuary, there, in part, to mingle with the rest of the shingle of the shore.

In these various ways—by the drift of the storm and tide, by the wash of the rain, by the force of the river-flood, and by the transport of the mighty glacier—these foreign stones have reached their present position in the shingle at our feet. They are of granite, felstone, quartz, porphyry, because these special rocks lie in the direction whence the glacier, the river, or the tide, moved to this spot. Had the hard rocks in that direction been flint or serpentine, marble or slate, all our foreigners would have been of these classes, instead of being what they are. And this is actually the law which regulates the presence and comparative abundance of the different finds of pebbles in the shingle beaches of Britain generally. On the coast of Dorset, where

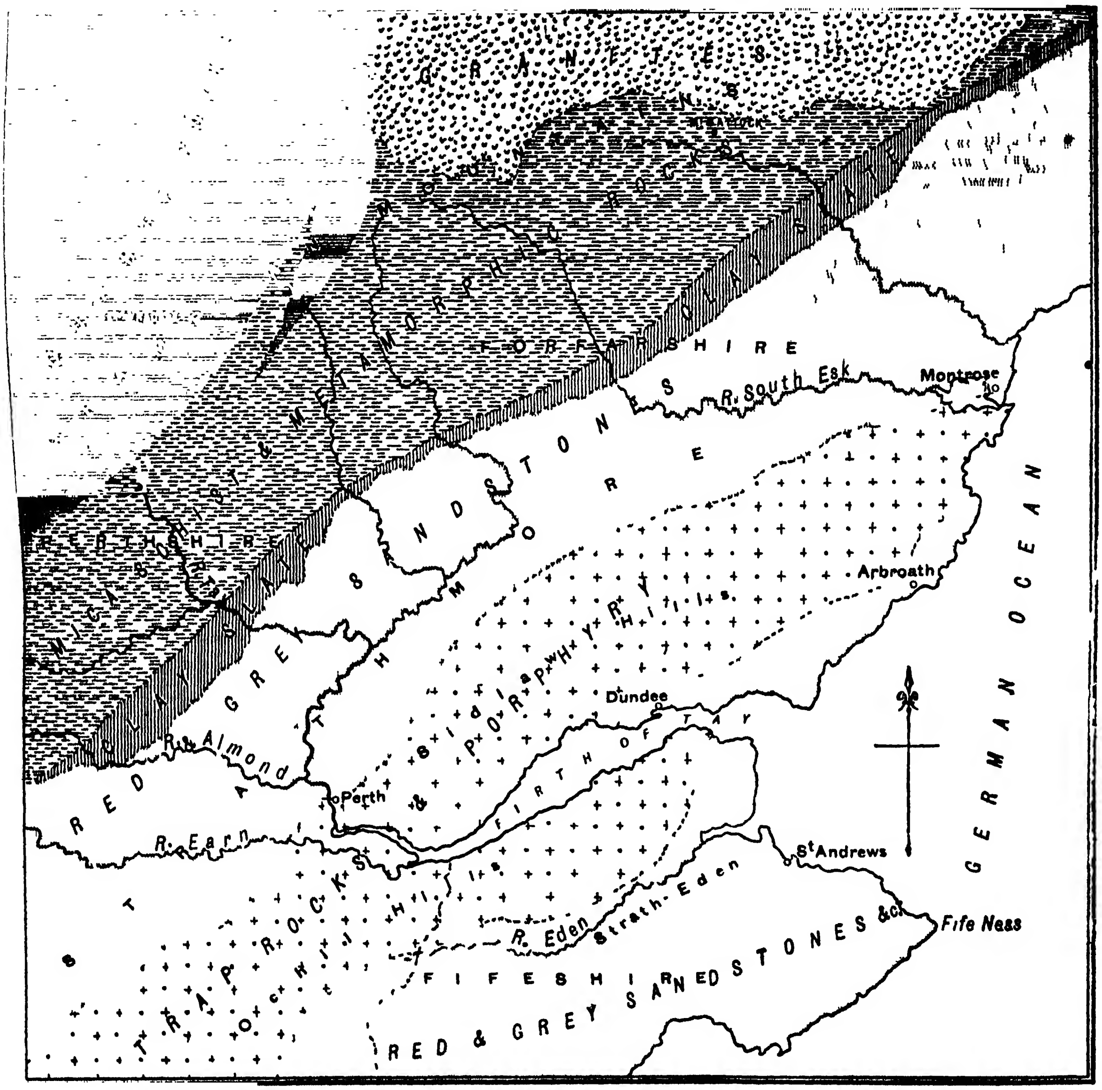


Fig 2 Sketch Map showing Distribution of Rock Formations North and North West of Fifeshire

the drift of the wind and tide is from the south-west, the hard grits, sandstones, and flint of the distant Devonshire coast preponderate to such an extent that the soft local rocks appear to be absent entirely. On the Brighton coast farther east, the flinty pebbles of the nearer chalk prevail. Each gravelly shore has its own peculiar association of pebbles, dependent solely upon the proximity of the hard rocks which furnish the several kinds, and the possibility and comparative ease of their transport.

It would be ridiculous to imagine that the pebble beaches exposed at low tide contain all the shingle that is lying off our coasts. On stormy days the back wash of the breakers rolls many of these pebbles down the sloping shallows into the deeper waters beyond the reach of the waves. There they are partly covered up and buried by the mud and sand washed down upon them. In this way our islands are surrounded by a fringe of submerged pebble-beaches, not only off rocky headlands, but in every spot to which a stone may be rolled, and where there is room for it to lie undisturbed.

In these sheets of water-worn gravel and sand, visible and submerged, we have the material for our puddingstone ready to hand upon our coasts. The next question is, by what possible process are these loose accumulations formed into solid, compact masses of rock?

To a certain extent, we have examples of the artificial manufacture of puddingstone frequently before our eyes. Taking advantage of certain chemical properties of lime, man has long ago learnt how to bind together loose stones into a solid mass. Most of us have watched with interest the workmen laying a floor of concrete, filling up the interstices in a layer of small stones with a fluid cement which soon hardens and binds the whole into a firm, stony sheet. In districts where building stone is dear, handsome houses are built of this concrete, formed of lime, sand, and the pebbles of the river-side. The common mortar which binds together the courses in our walls is another and a more familiar example of the same class. The calcareous cement used by the old Roman builders was remarkable for its hardness and durability, often withstanding the ravages of time better than the included stones themselves.

In binding together the loose gravelly material on the sea-floor, nature works in precisely the same way. The broken sea-shells, the fragments of coral, the waste of limestones and chalk-cliffs, and all the calcareous sediment washed down by the rivers, are mixed up with the sandy material, amid which the pebbles lie imbedded, and unite with it to form a limy cement which soon hardens itself into compact rock. But nature goes beyond man in this respect. By certain chemical changes brought about in her secret laboratory, she produces even siliceous cement of the substance of the very stones themselves, as it were binding them together by a mortar of glass.

By these varied processes nature is ever busy with the manufacture of puddingstone and conglomerate, off every rocky shore at the present day, ready for that future time when it shall be upheaved to form the rocky flooring of the continents to be. As she works now, so must she have wrought, since first the rain began to fall and the storms to rage. The ancient puddingstones of our museums are fragmentary relics of the off-shore pebble-beds of vanished lands, bits of visible history, as fruitful of interest to the thoughtful mind as the rusty coins and medals that recall the glories and decadence of the empires of old.

In the south-west of England there are few rocks that deserve the name of puddingstone, but in some parts of Wales it is abundant. On the picturesque Fans of Brecon, these old consolidated sea-beaches rise above two thousand feet into the air. Throughout the length of England, from Land's End to Carlisle, we find many patches of this rock forming rugged knolls. In the south of Scotland it runs in a long, broad band on each side of the great central valley. On the south it forms the edge of the southern uplands from Dunbar to Ayr. On the north it occupies much of the wide valley of Strathmore, and flanks the southern slopes of the Highlands from sea to sea.

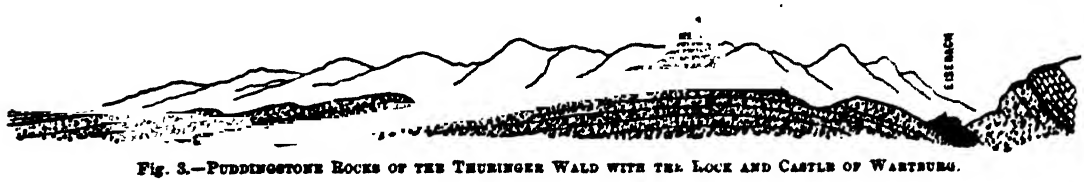


Fig. 3.—Puddingstone Rocks of the Thuringer Wald with the Lock and Castle of Wartburg.

On the Continent of Europe this species of rock

is even more grandly developed. Its intractable masses compose many of the rugged mounds crowned by picturesque castles that diversify the central districts of Germany (Fig. 3). In Switzerland it forms the outer zone of the Alpine region from Geneva to Constance, rising in Mount Pilatus and the Rigi to more than a mile-and-a-half in perpendicular height. Its consolidated pebble-beds, often several thousands of feet in thickness, stand up vertically on edge, irresistible proofs of the stupendous forces that called this magnificent mountain region into being.

A SHADOW.

By William Ackroyd, F.I.C., etc.

WHO has not glanced at his shadow cast by the sun, and with curious eye made note of its form and proportions, always grotesque, and at one time gigantic in its dimensions, at another dwarfed to the representation of a pigmy? As children we may have chased it, or like Alexander's horse, Bucephalus, been frightened by it; as boys, it may have been a source of dissatisfaction, more especially when some feature of clothing or gait has been exaggerated; and as men we have doubtless altogether ignored it; but with nothing have we become so familiar, and nothing have we come to regard as so unreal, changeable, and devoid of the properties which pertain to tangible bodies. Because of these qualities its name is in constant use metaphorically. A Government corrupt to its core is described by the historian as a shadow; the thin, pale man, wasted by disease, we speak of as the shadow of his former self; and to a Tennyson, concentrating a million years into a moment,

> "The hills are shadows, and they flow
> From form to form, and nothing stands."

It is of this symbol of the changeable and unreal that we have to speak, and we intend to tell of remarkable as well as common shadows, how they are produced, and what they are like.

Shadows are the result of the great law that light proceeds through a homogeneous medium in straight lines.* Hence, when an opaque body is held in the way of light there is darkness, or shadow, behind it, and the form of the shadow projected on to any screen placed to receive it is determined by the form of that section of the obstructing body which is at right angles to the direction of the light rays; hence the shadow of a ball is a dark circle, and if one were to bend the bare arm at the elbow and the hand at the wrist, as in Fig. 1, the shadow would be a fair representation of a swan.

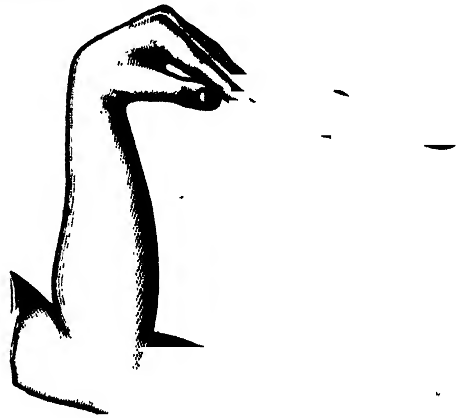


Fig. 1.—Shadow Swan.

These hand-shadows have always been a source of keen delight to children, because of the number of shapes one may represent by various dispositions of the hands when held up not far from the gaslight, and, perhaps, because the black moving things on the wall may be made a caricature of the real. Heads of animals of all sorts may be exhibited and made to open their mouths or prick their ears at pleasure, and the enjoyment reaches its height when by the judicious disposition of lights, and the co-operation of two friends of mature years, a Red Indian and a negro are exhibited jabbering in unknown tongues (Fig. 2).

Natural shadows assume a position of some importance, for wherever light can reach there they are sure to be produced. The shadows of lunar mountains,† or of Jupiter's satellites, are

* "Science for All," Vol. I., p. 190.

† "Science for All," Vol. I., p. 7.

interesting sights to the astronomer, and here below our own mountain shadows at times are remarkable things to see. Perhaps one of the most extraordinary mountain shadows is that of Adam's Peak in Ceylon. The peak rises abruptly from the low country to some 7,420 feet above the level of the sea, commanding a fine view of the island scenery to the south-west and north-west for a distance of fifty miles or more. The phenomenon of the shifting

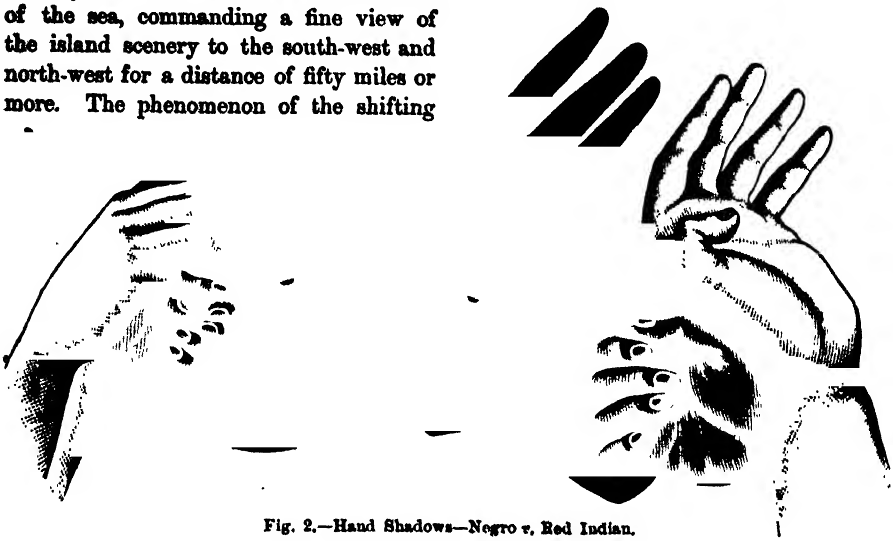


Fig. 2.—Hand Shadows—Negro v. Red Indian.

shadow of the mountain is thus described by those who have seen it. It appears at sunrise, an enormous elongated shadow, A B, projected to the westward over land and sea to a distance of seventy or eighty miles. As the sun rises higher the shadow approaches the mountain rapidly, and appears at the same time to rise above the spectator

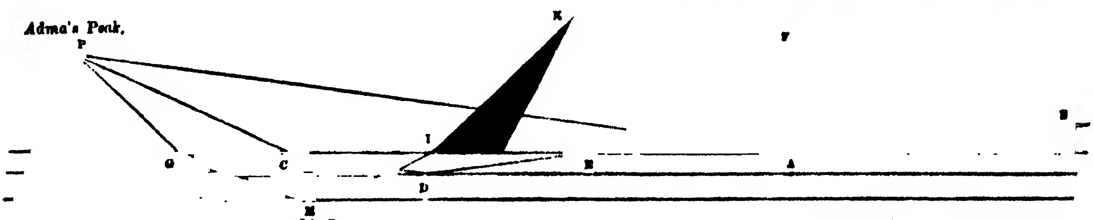


Fig. 3.—The Shifting Shadow of Adam's Peak, Ceylon.

in the form of a gigantic pyramid of shadow, I K, a veil of darkness suspended in the air. Each instant it appears to become more distinct, until suddenly it seems to fall back on the observer, and the next moment it is gone (Fig. 3). The Rev. R. Abbay, who has described the phenomenon, thus explains it. The temperature of the air at the summit of the peak is about 40° Fahr. colder than that of the country below, and considering the lower strata of air to be lighter than the upper, we have no longer that uniform density which is requisite for a ray, passing over the top of the mountain to the low country, to proceed in a straight line. We have, in short, the precise conditions for the production of the now well-known phenomenon of mirage. The rays from the rising sun coming over the mountain, P, in an oblique direction, P A, suffer total reflection in the direction A B; so, likewise, at subsequent stages of the sun's rising, the rays P C and P G are reflected in the directions E F and I K. We get thus, as it were, a reflected shadow, which is constantly altering its position until the sun has risen sufficiently high for its rays to pierce the reflecting strata of air over the low country to the west of the mountain. In Fig. 3 the shaded parts, B, F, and K, represent the position of the shadow at three different moments of time, from which it will be seen that, as it appears to rise, its base approaches the mountain.

Shadows, as we generally see them, are areas of darkness on the surfaces of solids; but smoke and dust particles, which readily reflect light, render shadow very distinct. In a smoky atmosphere the shadow of a house is seen in the air as well as projected on the road, the distinct line of division between the light and shadow being readily traceable. Mist is also a very efficient shadow shower, and probably the moving veil of darkness seen in the case of Adam's Peak is thrown on the morning mist which has not yet been dispelled by the solar heat rays; and similarly, in the case of the remarkable

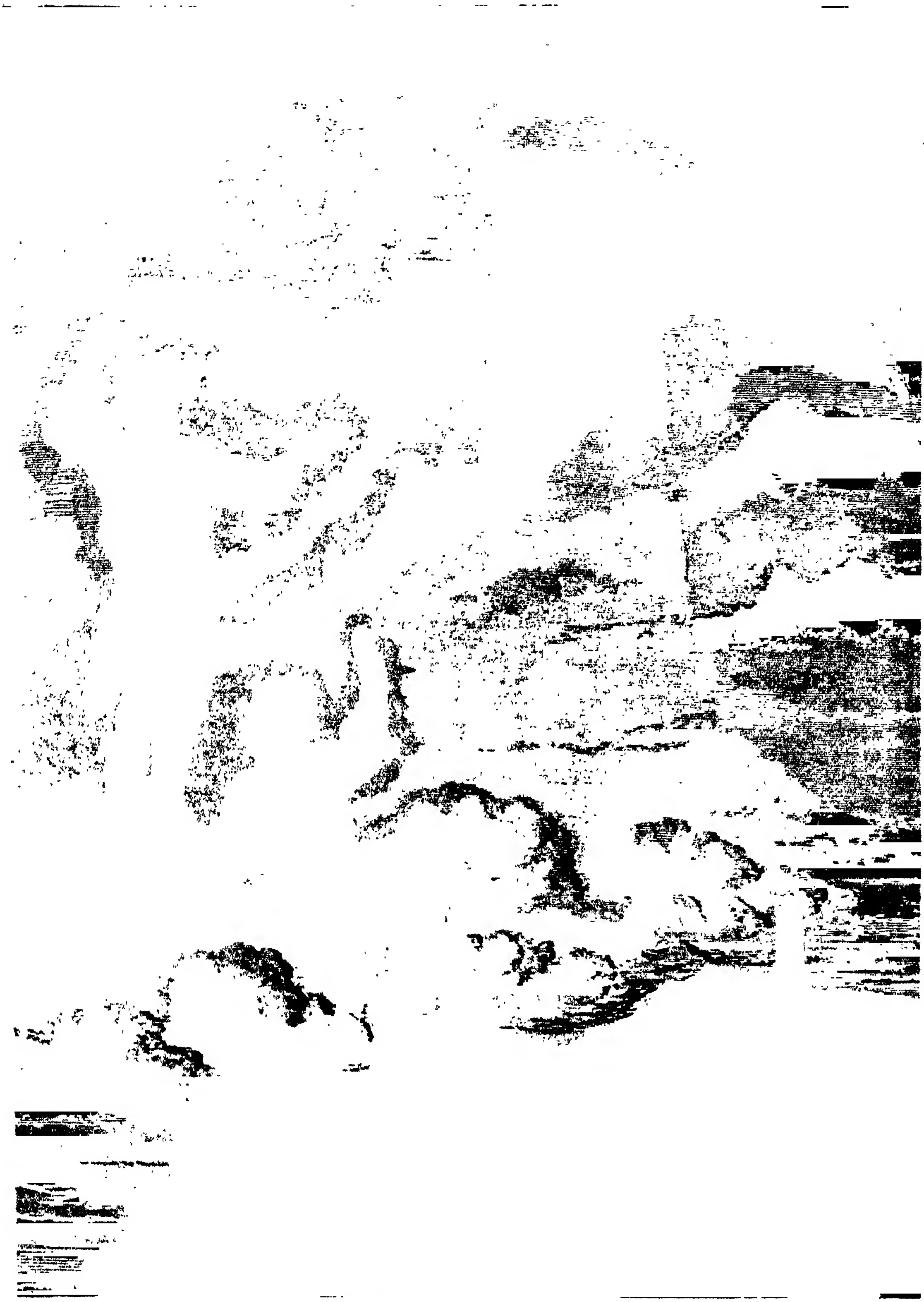


Fig. 4.—Spectre of the Brocken.

shadow known as the Spectre of the Brocken, the dense and hazy atmosphere surrounding the mountain summit forms a good shadow ground (Fig. 4).

The Brocken, one of the loftiest of the Hartz Mountains (3,417 ft.), has from the earliest times enjoyed pre-eminence as the seat of the marvellous. Here in times past the timorous peasant was wont to see, at break of day, black, gigantic forms, more fear-inspiring than any Oriental genii ever were. In his benighted state of mind he could but refer the effects he saw to magic, to that wonderful occult influence which enabled a Michael Scott to cleave a mountain and do other marvellous acts. And now the traveller is shown on the summit of the Brocken the Sorcerer's Chair and the Altar, huge blocks of granite; he stoops to drink at the Magic Fountain, a crystal spring; or, maybe, plucks up the anemone of the Brocken, and is told it is the Sorcerer's Flower. His next great desire is to see the Spectre of the Brocken, for his brain being uncobwebbed with ancient superstition, he perceives clearly that the spectre must be some natural phenomenon. He is successful in his efforts, and sees a most remarkable group of shadows of himself and comrades. Looking westward while the sun is rising, he observes gigantic forms of darkness which mimic every movement that is made; they seem far off, and yet are probably close at hand, and ere long have completely vanished. The phenomenon has been seen both at sunrise and sunset, and one persevering investigator, M. Haue, narrates how he was unsuccessful in seeing it until he had made no less than thirty morning ascents.

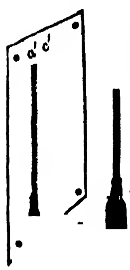
When a person's shadow is projected on to mist particles an accompanying effect is at times observed which might nearly have been predicted—the head of the shadow is surrounded by very large crowns of colour. It will be noted that in such a case we have precisely the same conditions as for seeing rainbows—viz., the sun behind, and the effect to be observed fair in front,* and the reader will have no difficulty in seeing, from what we know of rainbow phenomena, that if the observer's shadow could be cast in the same plane as the rainbow, the head of the shadow would occupy the exact centre of the gorgeous circle. It is seldom that complete circular rainbows are seen, but at such times a shadow of the observer is in the centre. Figure 14 (Vol. I., p. 197) illustrates a case of this kind, where M. Tissandier, having ascended in a balloon above the clouds, saw a circular rainbow projected on the vapoury atmosphere below, and fair in the centre was the shadow of the car and its occupants. The phenomenon which is known as Ulloa's Circle would appear to

Fig. 5.—Ulloa's Circle.

* "Science for All," Vol. I., p. 189.

be somewhat of the same nature, and the following are the circumstances under which MM. Ulloa and Bouguer saw it. During their stay in the Pinchincha they were one morning at daybreak on the summit of the Pambamarca. The mountain top was covered with a dense fog, which was gradually dispersed by the rising sun. While they were watching this gradual disappearance of fog and light vaporous clouds, one of the travellers, on turning his back to the rising sun, saw the appearance portrayed in Fig. 5. Standing apparently at a distance of twelve feet was an image of himself, surrounded by three concentric rings, shaded with different colours, while round the whole was a fourth ring of one colour only. The figure mimicked every movement of the observer, the rings keeping the shadow of the head as a common centre. It is a singular thing that each of the travellers saw only himself, and not a group, as in the balloon ascent we have just mentioned.

When two lights send their rays towards the obstructing body, a couple of shadows are thrown on to the ground, and one generally appears blacker than the other. An exact comparison of the



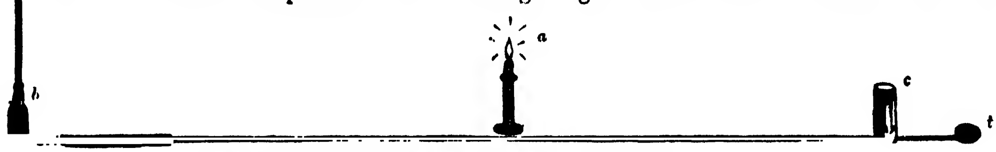


Fig. 7.—Count Rumford's Shadow Test of Luminosity.

two shadows may lead to precise information respecting the relative merits of the two lights themselves (Fig. 6). Since a perfect shadow is

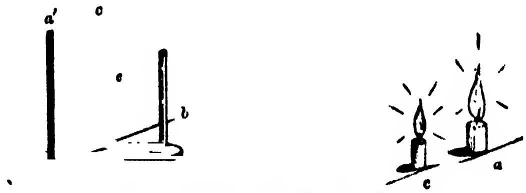


Fig. 6.—Intensity of Shadows affected by External Lights.

the total absence of light, it is apparent that the perfect shadows of *b*, produced by the lights *a* and *c*, ought to have the same degrees of blackness. But the shadows *a′* and *c′* are each illuminated respectively by the lights *c* and *a*, and are consequently much lighter than the perfect shadows would be. It is quite clear, therefore, that if the lights *a* and *c* were the same distance from the light obstructor *b*, and if, moreover, there were a difference of illuminating power in *a* and *c*, then there would be a difference of blackness in the shadows, that shadow being the blacker which was illuminated by the weaker light, and in the case in point *c* would be the weaker light. More precise information still could be obtained about the relative merits of the lights *a* and *c* by utilising the law of inverse squares explained in a former paper.* This was done by Count Rumford, and the reader will now readily understand the principle of his shadow photometer or light-measurer. We shall be best able to illustrate his method by a simple example. Suppose we required to know the relative illuminating powers of a paraffin oil lamp and a common candle, we might proceed in the following homely fashion (Fig. 7):—Pin a sheet of white paper against the wall as a screen to catch the shadows; place a rod of cane in the neck of a bottle, *b*, for a shadow producer; and have a tape measure, *t*, with the free end of the tape pinned down at the bottom of the paper, so that distances from the screen may be readily measured. Now bring the lights to be tested alongside the tape, and by putting the stronger light farther from the screen than the other, the distances may be so adjusted that the shadows *a′* and *c′* are both of the same degree of blackness. Suppose these are the distances of the lights from the screen :—

Candle	. . . .	7 feet
Oil Lamp	. . . .	12 „

The squares of the numbers, viz., 49 and 144, would express the relative illuminating powers of the two lights; whence it would appear that the oil lamp is not far short of being equal in illuminating power to three such candles, as $\frac{7^2}{12^2} = \frac{49}{144} = \frac{1}{2 \cdot 93}$.

Shadow phenomena are somewhat different when the sources of light are a luminous point and a luminous surface respectively, as, *e.g.*, a brilliant star and the sun. When a point of light is used, the usual black shadow is fringed with colours, which form a gradation between the darkness

* "Science for All," Vol. III., p. 263.

within and the bright space without; but when a surface of light is employed, the complete shadow, or *umbra*, is surrounded by a less complete shadow, or *penumbra*. As we have said, a brilliant star or planet is an example of a point of light, and Sir John Herschel has observed that Venus, when at its greatest brightness, produces a shadow bordered with coloured fringes, if the shadow be cast upon a white screen within a one-windowed room, and under favourable circumstances as to twilight. For experiments of this sort an artificial point of light may be thus produced:—Admit the parallel rays of the sun into a dark room through a hole in the shutter, and then bring the rays together by means of a lens of short focus. The small image of the sun which is thus formed at the focus is a brilliant point of light.

These coloured fringes, running close and parallel to the edge of the shadow when a point of light is used arise from what is known as the diffraction or inflection of light. We have learned in a former paper (Vol. I., p. 362) that light is propagated by ether waves, and these waves, when passing round the corners or edges of opaque bodies, interfere with each other, and produce by their accordance and discordance (Vol. I., p. 363) the blue, yellow, and red fringes we are speaking of.

Fig. 8.—Formation of a Penumbra.

The production of a penumbra is easier still to understand, and may be thus explained:—In the experiment illustrated by Fig. 6 bring the lights *a* and *c* nearer to each other, until their shadows overlap. There is now a middle space of darkness, the *umbra*, *u* (Fig. 8), and on either side of it, shadow less complete, the *penumbra*, *p p'*. The light from neither candle reaches *u*, whereas the penumbra is illuminated by one or other of the candles.

The penumbra which surrounds a planetary shadow is of exactly the same nature as the foregoing, and is produced in the same way (Fig. 9). For if S represents the surface of the sun, and E the earth, it is evident that the rays emanating from *a*, and those emanating from *c*, shine upon E (Fig. 9), in a precisely similar manner to the

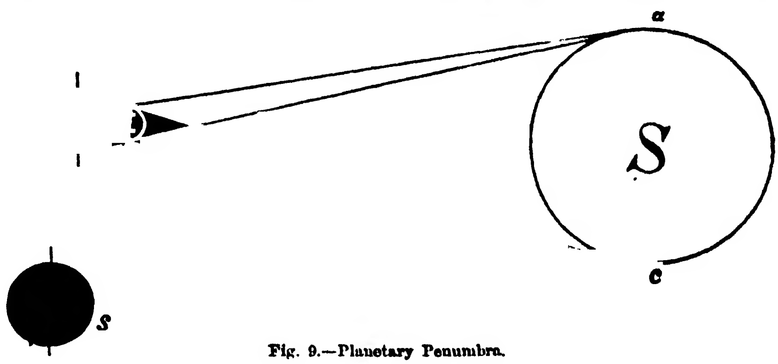


Fig. 9.—Planetary Penumbra.

rays falling on *b* from *a* and *c* (Fig. 6), and a dark shadow, *u*, is formed along with a penumbra *p p'*. The surface of the sun, however, is a collection of luminous points like *a* and *c*, and it will readily be perceived, what cannot so well be represented in a sectional diagram, that the shadow of the earth is a cone of darkness, *u*; and, further, that if a screen of immense size could be placed at *p p'* to receive the earth's shadow, we should have, as at *s*, a central dark circle surrounded by a ring of penumbra. The only screen that ever shows us this darkness is the moon, and at such times it is eclipsed.

From all that has been said concerning natural and artificial shadows, we learn the simple lesson that wherever light can reach there shadow may be produced—on a grand scale when the light-obstructor happens to be a planet, and on a minute scale when the tiny blood-vessels of the eye are the light-obstructors giving rise to what we have described in another paper as Purkinje's figures (Vol. III., p. 116); and a knowledge of even so simple a natural fact cannot but prove a source of pleasure when it is utilised for the explanation of phenomena such as we have dealt with.

TABLE-LANDS, AND HOW THEY WERE FORMED.

By Professor P. Martin Duncan, F.R.S.

There are many parts of central and northern England, where there are upland districts some hundreds of feet above the level of the rivers, and which extend for many square miles. These broad moorlands, comparatively flat on their surface, are surrounded on all sides by steep places and valleys, and look as if they were parts of the country which have been lifted up beyond the ordinary level. They have watercourses on them, there are often peat beds there, and the heather grows on the wreckage of the sandstones and grit which form the sub-rock. From being at a considerable elevation, and comparatively, and in most cases quite, treeless, the air is colder on them than in the valleys; and even when there is a sultry summer's night in the dales, the temperature is very much less on the high land, whence radiation into space occurs during the long hours of the still darkness. There are then places close together, where there are different climates, and there is no doubt that the high moorland decides the production of mist, cloud, and rain, which would not occur were the country an ordinary rolling plain. The sides of these uplands are often very steep, and the bold slabs of rock which form the hills, stand out on their flanks, so that the substance of which these elevated lands are formed can be studied. Again, these slabs which form parts of strata, are, to the untrained eye, in long horizontal layers one over the other, but the geological surveyor shows that they are in curved lines, the bends occupying long distances so as to be almost imperceptible in some cases, but visible enough in others.

There is a fine example of a small table-land of this kind in Derbyshire, and it is in the district of High Peak, where a peculiar geological formation of grit, or sandstone with visible grains, has to do with the formation of broad plateaux. The High Peak, or Kinder Scout, has an almost flat top of six miles long by two in breadth, and its edges are remarkably irregular, and jut out and come in, in a very sinuous manner. These edges, as the ascent is made, are seen to be parts of a great cliff of sandstone rock, covered by about twelve feet of peat, and there are watercourses steep-sided and very winding in it. There is a splendid view from the top, and the surface at one's feet claims attention at once, for there is evidence before the eyes how this part of a once massive mountain has been worn down flat. Every where there is no running water, and on the top of the little table-land, there are monumental-looking pillars of stone, more often broader at the top than at the base. They are nature's monuments over and about a ruined country, and their top indicates the former level of the district. Worn by the slow activity of the air, sun, cold, and rain, and not by the sea or by running water, these stones, so frequently attributed to human agency, make the subject of the table-land all the more interesting.

Standing on the Malvern Hills, the spectator on looking to the west, towards Wales, sees a tumbled mass of country before him, with rounded hills and deep dales in abundance, and in the far distance the tall, dark hills of the Black mountains. These are flat-topped, and their table-land-like character is evident. Turning round and looking eastwards, a very different scene bursts on the eye. The great plain of the Severn is at the foot of the hills, studded with villages, dotted with towns, and magnificently wooded. In the remote distance, a line of cliff-like country is seen, with a flat top, and it is the escarpment of the Cotswold Hills, on the top of which is a great table-land with a slight slope to the east. This is a plain on the top of the escarpment with valleys in it, and it extends miles and miles to the north, and on all sides. An escarpment looks like a sea-side cliff, but it has not been produced by the same agencies, and it is the result of the wear and tear of the rocks by the gentler influences of the atmosphere, rain, running water, and heat and cold. A cliff, in addition to these wreckers, suffers from the action of tide and wave carrying vast bodies of water, sand, and stone in contact with its base.

These uplands, or comparatively level, elevated districts, standing on all sides above the ordinary country level, and more or less flat on the top, are the simplest examples of some very grand and important physical features of the great land masses of the earth, and which are usually called "table lands," or perhaps more scientifically, but not more expressively, "high plateaux." The word table, of course, refers to the flat top placed high above the floor of the country, and the notion of legs must be replaced by the truth that a vast mass of

earth exists as a pedestal. In studying table-lands, however, it is necessary not to be too much attracted by the presumed excessively level or flat table-like top, for this rarely occurs, and indeed some table-lands have mountains and volcanoes arising from them, and in their midst, and lakes on their surface. It is now necessary to consider the different kinds of uplands in different parts of the world, so as to attempt an explanation of their occurrence.

The great uplands of Asia, north of the Himalayan Mountains, extend along nearly 30 degrees of longitude, from the sources of the Oxus River to those of the Hoang Ho, or Yellow River, of China. Their northern face is the Kuenlun range of mountains, and the southern part fits in here and there, amidst the great Himalayas, which may be taken to be its southern boundary, and still farther south are the plains of India. These plains have not a greater altitude than 1,200 feet above sea level; then the Himalayas tower up in several parallel series or ranges, running north-west and south-east, more or less, to a height of from 20,000 to 28,000 feet. There is not a corresponding descent farther north, for the great table-land is there, rising even before the last peaks are passed, to a height of 16,000 feet. It is a land where the moisture of the air is slight, and where the temperature is low. There are lakes, and in one district—the Hundes—remains of volcanic activity. Nothing can be more striking than the difference between the upland climate and its fauna and flora, and those of the hot plains of India.

Fig. 1.—Basaltic Plateaux of the Coiron. (*From Scrope's "Geology of the Extinct Volcanoes of Central France."*)

Vast districts in Central and Western India are occupied by remarkable flat-topped hills, many of which are so extensive that they merit the name of table-lands. Indeed, a considerable portion of the surface of 200,000 square miles is thus occupied. Along the western sea-board of the peninsula of Hindostan towards Bombay, there rises a vast escarpment, looking like an inland cliff, and it leads to the uplands, called the Syhadri range. Terrace after terrace, flat-topped and precipitous, rises to the height of 4,000 feet, and the hill country looks down on the hot tropical slip between it and the sea, or the Koncan. On the upland, and extending for thousands of square miles, are flat-topped spots, separated by deep gorges, or river valleys, with steep sides. To the north, on the river Nerbudda, and to the east in Hindostan, scarps are also to be seen, and the so-called Ghâts in Eastern and Western India are mostly in relation to this assemblage of great flats, which before the rivers wore their way down

and produced their valleys, were one vast table-land. The vegetation of this district is peculiar: it is a treeless land as a rule, and covered with long grass, or rather, large trees are excessively rare, and those which exist, in damp situations near the sea-coast, are not evergreens. In all the cold season from November to March the surface is a uniform straw colour, there being but few green spots to break its monotony of tint. From March, when the grass is burnt, until the commencement of the rains in June, black soil, black rocks, and charred tree-stems give a peculiar aspect of desolation. During the rainy season the surface is covered with verdure, most beautiful in many places. On a grand scale is this series of table-lands, great rivers pass through it, and its thickness is as remarkable as its surface. Mile after mile the flatness is monotonous, but on the whole there is a slant from west to east. No great lakes exist, no volcanoes occur, but the whole table-land is volcanic in its origin, and there are many remains of old lakes and of a few extinct volcanic vents. It is a repetition of the scenery and physical geography of the Auvergne on a very grand scale, but the visible extinct volcanic cones of Central France (Fig. 1) are not represented in the far east. One remarkable lake must, however, be noticed, as it relates to the cause of this table-land of the Deccan, that is to say, of the districts of Central and Western India south of the great Vindhyan range. It is in the midst of the district, and about half-way between Bombay and Nagpur. There is a circular hollow about a mile across, and from 300 to 400 feet deep, and at the bottom is a shallow lake of salt water without any outlet. The water contains a salt of soda, and whilst the sides of the lake are mostly on a level with that of the surrounding country, in one place there is a rim like that of a volcanic crater, made up of volcanic rock or basalt; moreover, the inclination or dip of the sides near the lake, is from it outwards. "It is impossible," write Medlicott and Blanford, "to ascribe this hollow to any other cause than volcanic explosion."

The map of North America and the results of the surveys, show that the shape and configuration of the western part is the result of the formation of three important, and more or less parallel and distant, mountain chains. There is one, the coast range of California; eastwards of it is the second or the Sierra Nevada, and then hundreds of miles off are the Rocky Mountains. Now between these last two is the great country of the cañons (Vol. I., p. 214–5), an upland cut into by valleys or cañons of vast depth and very precipitous. This over-drained country, bounded by mountain chains, is a high table-land, and geology has proved that once it was a great lake district, situated not much above sea-level, and hemmed in by low chains of hills; upheaval and the present state of things followed.

Mexico is the country of table-lands, and its geography, climate, and peculiar animals and plants, are singularly influenced by their great development. Taking that part of Mexico near the Gulf of Mexico, as our example, the city of Vera Cruz and the country inland first require notice. The country around that city, and extending inland for some sixty miles, is comparatively low, and then an ascent commences, gradually at first and then very steeply. In some places a succession of terrace-like steps leads up to the high land, and the ascent is, of course, then rather gradual; but in other parts the country rises from 5,000 to 6,000 feet in a distance not exceeding ten miles. The practicable roads for carriages are few, and in many places vegetation is not seen on the scarped face of the rock, but only in the crevices and along the course of the torrents and dry water-courses. This ridge or escarpment is about 600 miles long, and the distance between it and the coast is, in some places, three times as great as it is in the neighbourhood of Vera Cruz. It constitutes the eastward edge of some vast elevated plains or table-lands which extend westwards, and form the greater part of Mexico proper. These table-lands are (between 19° and 20° N. lat.) 360 miles long from east to west, and reach over the continent to close to the Pacific, when diminishing gradually in altitude, they end in a low land whose tropical vegetation testifies to the altered climatal conditions. The extent of the table-lands north and south is great, and indeed the northern boundary is not defined, the uplands being connected with those of the United States. But to the south, the plain of Mixtecapan joining on to the low lands near the east coast, crosses the isthmus at about 18° 30′ N. lat. to the Pacific Ocean, and forms the boundary of the high land. The table-lands are thus bounded on the east and south by plains and broken country, and on the west also, whilst they are continued northwards. It is a vast upland region, and rises as a broken plain to a height of 7,500 feet above the sea eastwards; to the north the height of 4,000 feet is attained, and to the south about 3,000 feet,

whilst there is a gradual slope to the Pacific coast. Stretching across the continent from the Gulf of Mexico to the Pacific, a slip of low ground only intervening, and possessing a totally different climate to the torrid and moist regions of the isthmus between the Americas, this table-land is a physical barrier between the great majority of the animals of North and South America, preventing their roaming and slow emigration. There are large streams intersecting the table-land, and very high mountains arise from the surface here and there or in lines; moreover, volcanoes on the grandest scale rest upon it, and there are some large, important lakes placed there. Hence these Mexican table-lands resemble a part of a continent with its plains, mountains, and lakes upheaved far beyond the level of the sea. The mountains are in chains on the surface of the table-land, and whilst some are at its very edge, others traverse it. The volcanoes are not in chains, but are more or less solitary. Thus, the edge of the table-land which is to the west of Vera Cruz has a series of hills and mountains on it, and they rise at a height of more than 5,000 feet above the level of the sea; one attains the height of 13,415 feet, and another (Orizava), of 17,373 feet above sea-level. The chain becomes one of hills to the north, which at last sink to the ordinary level of the plain. The country or table-land to the west of this boundary chain, and which has been noticed to be 360 miles across, is divided into four by ranges of hills, which rise about 2,000 or 5,000 feet above the level of the plain, and by higher mountains. Towards the east this upland is sterile, from the volcanic nature of the soil, but westwards it becomes fertile until the mountains are reached to the west. These contain one peak of 15,704 feet, and the highest mountain in Mexico, the volcano of Popocatepetl, which is 17,880 feet in altitude. The neighbouring plain to the west is 7,480 feet above the sea, and on the north the plain ascends even to 9,000 feet; but the westernmost part or that part which reaches within thirty miles of the Pacific Ocean, is not as plain-like as the others, but is broken up by low ranges of hills covered with verdure. All around this great system of uplands there is a more or less steep ascent formed by an escarpment. As might be expected, the climate on the table-lands and that of the belt of low land which environs them at least on three sides, differ much, and the hot countries, or Tierras Calientes, washed by the seas on either side of the continent, are readily contrasted with the colder and in some instances almost frigid uplands. The mean summer temperature characteristic of the moist torrid hot regions is about 82° Fahr., and towards the hills the mean annual temperature is 77° Fahr.; the rain-fall is moderate, and occurs within certain months, and the vegetation is that of the warmest tropics. On the other hand the climate of the table-lands is temperate, and varies with the elevation of the country. Those to the west of Vera Cruz have a mean annual temperature of 62° Fahr.; in winter the freezing-point is very rarely attained, and indeed all the lands about 5,000 feet above the level of the sea have a temperature between that just stated and 68° Fahr. There is not much difference between the summer and winter temperatures, and hence all those vast districts are decidedly colder than the others; they are called cold countries, or Tierras Frias. The amount of rain-fall is not great on the table-lands, and the soil is mostly porous, so that drought occurs often, and with the comparatively low temperature produces a very different vegetation to that of the plains on the sea coast; for the cactus tribe predominates, trees being almost entirely restricted to the sides of the hills. The very elevated uplands are still colder in their climate and more sterile, but some of the lower lands are fertile, and yield fine crops of cereals.

It must be noticed, however, that artificial irrigation produces wonderful crops in some places, and that certain natural gulleys, formed by rain and running water in a very loose soil, and which are called barrancas, have trees on their sides of vigorous growth, and a more genial climate than the land they intersect. But the most vigorous upland vegetation differs remarkably from that of the coast line. To the south of Mexico are the table-lands of Central America, where those of Guatemala merge into the high land of Yucatan. The table-land of Guatemala is especially interesting on account of the relation which some of the grandest volcanoes in the world bear to it. Near the town of Guatemala, on the northern borders, the table-land rises to 5,000 feet above sea level; but farther north it is still higher, and then the height gradually diminishes, until the wide and deep valleys are reached, which are to the south of the Mexican uplands. No great range of mountains traverses the upland, and only low hills occur. But towards the Pacific side, the slope down to the low plain which borders the coast is very steep and high, and a few lofty volcanoes,

reaching 12,600 feet in height, stand on the edge of the descent. The escarpment which thus separates the shore from the upland, is wall-like, and about twenty or thirty miles from the sea. Here, again, the lowlands have a very damp and torrid climate, whilst the comparatively treeless table-lands enjoy a perpetual spring, the thermometer hardly varying throughout the year. Lakes exist on these table-lands, and that of Peten in Yucatan is seventy miles round; there is one in Guatemala, near the western edge of the upland, and it is remarkable for its great depth and neighbourhood to a volcano; and there is another eighty miles round it to the north-west of the town of San Salvador. Finally, in addition to the volcanoes and lakes, there is a geyser on the table-land which ejects—according to Haefkins—boiling water to a height of twenty or thirty feet.

The system of table-lands in South America is included within the great chain, or the Cordilleras of the Andes. The mountain mass forms two or even three vast ranges, which combine here and there and then open out; and the valleys between them, vast in extent, are not at sea-level, but their surface is as high as the tops of many European mountains, and forms table-land. Thus two of the great ranges are nearly side by side, where they enclose the immense valley of the Desaguadero and also the great lake, Titicaca. This upland has an area of 16,000 geographical square miles, and is between 12,000 and 13,000 feet above the level of the sea. The lake is twenty times as large as the Lake of Geneva, and is in the midst of a most interesting country, full of the evidences of a former high civilisation. Finally, a ridge of hills runs across this upland, reaching some 3,000 or 4,000 feet above its level.

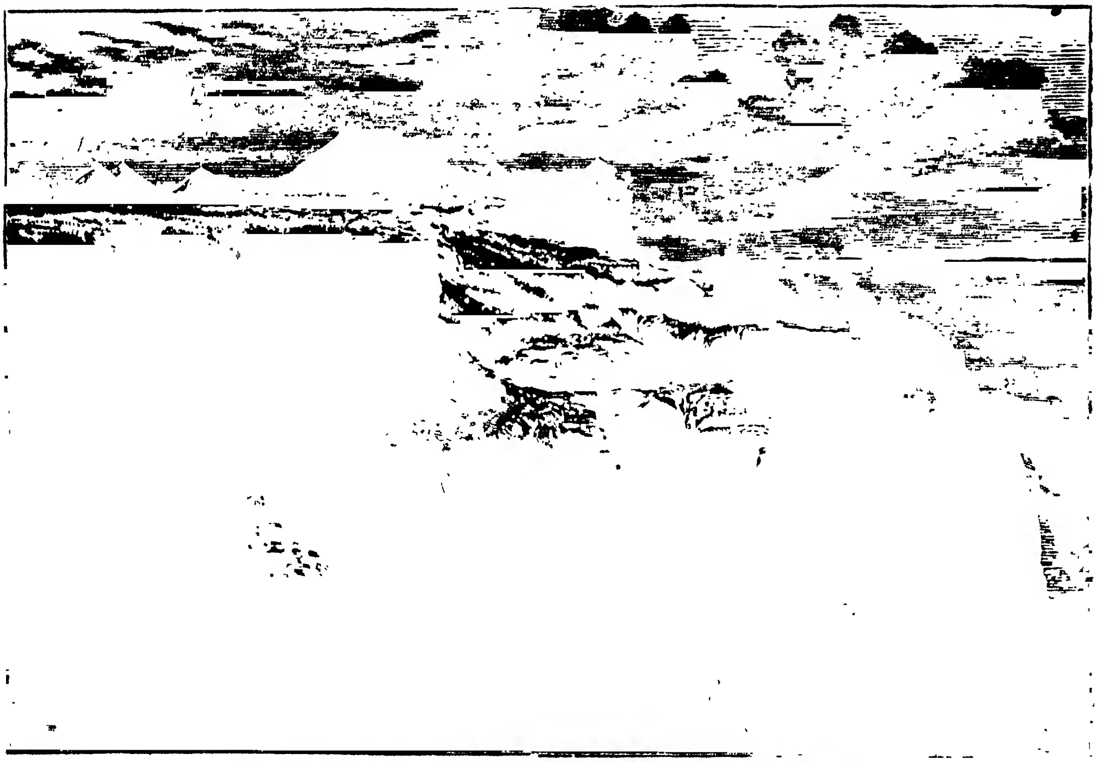


Fig. 2.—Table-Land of Magdala. (From Stern's "Captive Missionary in Abyssinia.")

Still to the north there is the well-known table-land of Quito. It is formed, like the others, between mountain ranges. This upland, at an altitude of 9,500 feet at least, stretches southwards for nearly 4° of latitude, and is in relation to some of the grandest volcanoes in the world. Chimborazo and Carguairago and others flank the plain, and this scenery is repeated still farther southwards. Here, again, the climate of the uplands differs entirely from that of the sea coast, and different groups of plants and animals exist close together and under very diverse conditions.

In 1868 everybody was reading of the gallant

deeds of British soldiers, and of their opponents, the Abyssinians, on the plateaux of their mountainous country. Magdala was on one of them (Fig. 2), and the greater part of the scenery of the country, which was illustrated by the scientific and artistic part of the expedition, was found to consist of vast heights and breadths of flat-topped hills separated by very deep ravines or gorges. In fact the whole country, intervening as it does between the borders of the Nile and the east coast of Africa, rises abruptly from the low country bordering the Red Sea and the Indian Ocean, and slopes more gradually on the west, where the branches of the Nile have cut out deep valleys. Blanford says be traced on the eastern outskirts of the region, and that the plateaux themselves are often covered with old volcanic lava flows.

Farther to the south, on the northern part of Natal, the distinguishing feature of the landscape is the presence of isolated hills on a high plateau, from which they rise some 2,000 feet. The plateau is about fifty miles in length, and around it are other uplands which have been worn by rains and rivers, and are separated into a number of small table-lands. The level appearance of the top of the elevated country is, as in Abyssinia, and in central and western Hindostan, evidently due to volcanic flows which covered the country far and

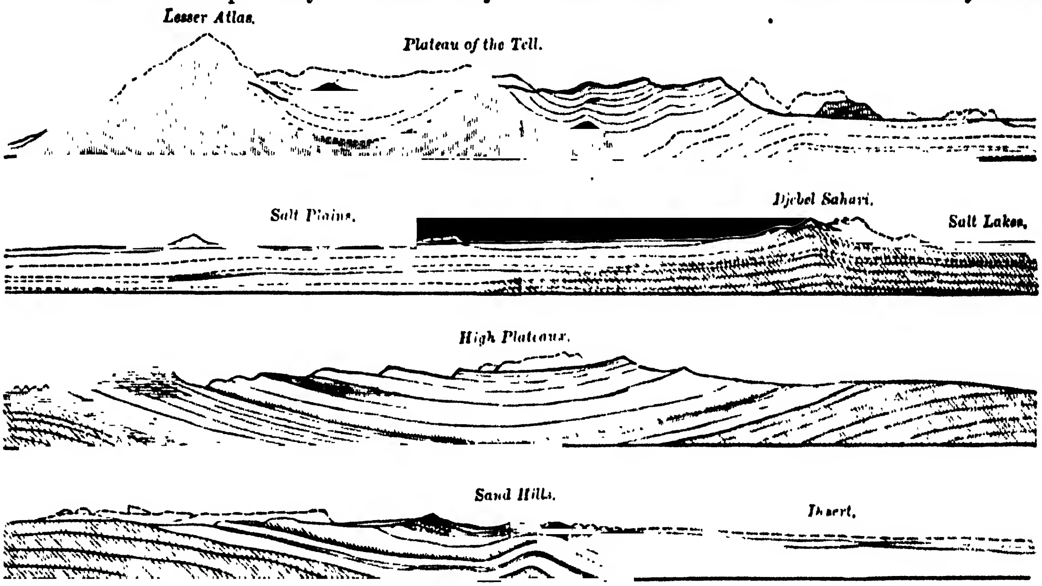


Fig. 3.—Section across the Atlas Range. (*From "The Quarterly Journal of the Geological Society."*)

hat the average height of the range of hills which eparates the streams running east and to the 'est, is about 8,000 feet, and that the greatest ltitude is 2,000 feet more to the south. There many plateaux of considerable extent are more than 10,000 feet above the sea. They are deeply seared by gorges, some even 3,000 feet deep, and some close to Magdala impressed every one who saw them by their great depth and the excessive steepness of their sides, their breadth being small in comparison. The wear and tear going on in the gorges, by the denuding action of the atmosphere and heat, rain, and running water, is vast, and it is evident that formerly the gorges did not exist, and that the plateaux were continuous as larger table-lands. It is important to notice that enormous amounts of former volcanic action are to wide, as a succession of sheets, one over the other. The base of the country is formed of sandstone, and on it is this trap or consolidated lava. At the south-eastern extremity of this plateau, on the frontiers of Zululand, there is a district where the evidences of volcanic action are present, for there are an extinct mud volcano and upturned layers of rock altered by heat. In Zululand many of the valleys are 2,000 feet deep, and their sides lead up to table-lands on which lava or trap rests, as a cap to the sandstone rock of the country. The valley of the Tugela is an instance.

Table Bay, the harbour of the Cape of Good Hope district, receives its name from the flat-topped mountain close by; and this shape is excessively common amongst the hills of much of South Africa. Whether rising suddenly from a wide

plain, or from deep and narrow valleys, the characteristic high lands stand up as a succession of terraces, capped by a comparatively level surface of great extent, or an escarpment leads at once to the table-lands. Most of the pedestals of, and often the whole of the uplands, are formed of sandstones, or they may be capped by a layer of dense basalt or old volcanic outflow.

On looking at a map of North Africa, it will be noticed that the great desert of Sahara is separated from the Mediterranean Sea by the Atlas range of mountains, which does not arise suddenly and precipitously from the desert on the south and the marine tracts on their north. On the contrary a number of uplands succeed each other, gradually leading to the more mountainous regions, and they constitute a region of high plateaux or table-lands. These uplands present vast barren surfaces, interspersed with little salt lakes or *chotts*, are without trees, and the hill-sides rise precipitously from them. But here and there, placed high up, and as it were on a pedestal of high land, are cedar forests, which have escaped the axe of the Arab, and these fine trees flank many a valley leading from the table-lands to the plains. Marvellous is the contrast between these lovely forests and the desolate plains surrounding and leading up to them, and the arid deserts to the distant south.

On travelling from Algiers to L'Agouat in the Sahara, after the low land of the plain of the Metidja is traversed, the slopes of the Lesser Atlas range are ascended, and after passing upwards between 3,000 and 4,000 feet, the rounded summit is seen. Beyond and southwards no higher ground is met with, but a long stretch of comparatively level country exists, called the Plateau of the Tell. This is an irregular table-land of an average height of 3,500 feet, and about 30 miles across. At the southern side of these uplands there is a slope down to 1,800 or 2,076 feet, and there are the broad salt plains of what is called the Northern Sahara, and far away to the south is a low mountain chain, the Djebel Sahari. This leads to a wild, broken country of salt lakes and of masses of rock salt, at a height of nearly 3,000 feet, and there, at a still higher altitude, are the High Plateaux of the region surrounded by escarpments, and forming a broad plain of thirty-five miles across, and 3,700 feet above sea level. Then the descent begins, flat-topped hills being common, until at last the great desert is reached, some of which is at, or below, sea-level. Thus the Atlas range near Algiers has mountainous peaks running in parallel lines, and between them, not higher peaks, but a high and comparatively flat table-land divided into three portions, the central being the lowest (Fig. 3).

There are, as may be gleaned from the examples given in the illustration of table-lands, several varieties of them, and it may be presumed that they were not all produced in the same manner. Those of our own country may be taken as instances where river action has formed gorges and valleys, and the denuding action of the atmosphere has assisted in their widening. The wear and tear have been great in the valley, but not as great on the broad hill-tops, where huge stones, often and erroneously attributed to the Druids, remain piled up above the level of the table-land, as monuments of an age when the whole country was higher, and the dense grits and sandstones reached up many yards above the present worn-down level. The influence of sub-aërial denudation in wearing down and sculpturing the district, into its present features, is evident, but it is equally clear that the peculiar mineralogical nature of the layers of the rock of the country, has had much to do with the formation of the flat-topped hills. The atmosphere acts chemically and mechanically on exposed ground, the oxygenation of certain minerals is constantly proceeding, and is assisted by the moisture of the air, or by dew and rain. All air contains a small quantity of carbonic acid gas (never under three parts in 10,000), and this assists the oxygen in weathering the rocks, so that portions rendered soluble are readily removed by rain. The sun assists in this, for its heat and light render the chemical activity all the greater; and the night's cold and winter's frosts add to the destructive power. Portions of rock expand in different degrees under the influence of the sun's heat, and contract as irregularly whilst cooling: and the expansion of freezing water in cracks is followed by shaling off flakes and large pieces of rock, during the thaw, and all these causes produce loss of substance. Again, wind, especially when it drives sand with it, carries off and wears the rocks; and, finally, rain, and running, and sinking in water, carry off the products of all the sculpturing. Grain by grain, day by day, century after century, the surface-wearing proceeds, and the top of the country, and its valley sides and floor, are gradually removed, planed down, flattened, and widened respectively. Limestones, granites, and clays wear down in time, and form hills of a definite shape, but not flat-topped ones. On the contrary, sandstones and grits, which have a flaggy

nature, wear flat at the top and into gullies at the sides. Again, many rocks have been poured out on the earth by volcanoes as lava-flows, and have consolidated into geometrically-shaped layers, called basalt or trap. These hard, glassy rocks wear in the long run, but more slowly than most others, and retain a flat surface. If they are placed on other rocks they protect them more or less on the top, but the sides fall away, crumble, and are eaten into by rain and rivers, and, finally, more or less isolated table-lands are formed. It is this very unwearable nature of the top of volcanic layers, and the more ready wear of the under rock or of its sides, that give the special landscape of high separate table-lands to those districts in central and western India, Abyssinia, Zululand, and Natal, which have been noticed. Denudation, then, of the top and sides unequally, and the particular nature of the rock, decide the presence of table-lands in some instances; and nothing can be more overwhelming to the mind, than the attempt to estimate the time which these lands took to wear asunder, and to become lowered (high as they are) as well. There is another agent which has to be considered, even in the formation of these table-lands of denudation, and it refers also to the next great altitude of "intra-mountain" table-lands.

There is a kind of sameness in the position of the great table-lands of the Himalayas and Tibet, of the Atlas, and of the Andes, for they are situated in the midst of the regions of the highest peaks, and really form large parts of the mass of the mountains, having great length, breadth, and height. Differing in their climate and vegetation from the plains at sea-level, these table-lands have been elevated subsequently to the process of that curving and bending of the strata which constitutes the first stage of mountain-making. Earth-sculpturing and valley-making had proceeded among the mountain masses before most, if not all, of the table-lands of the series now under consideration existed. On examining the layers of earth of the Tibetan and intra-Himalayan uplands, they are found to contain fossils of animals which lived late in the geological history of the world, and after there had been a Himalayan chain at a low level. Subsequently came a great upheaval, and 12,000 feet at least were added to the height of that enormous earth-mass. So, in the case of the Andes, the elevated plateau of Lake Titicaca was once at or below sea-level, and the upheaval of the chain, and really of the whole of that part of western South America, produced the scenery of the lake, plain, and mountain towering over all.

The comparatively late upheaval of the old plains of the area of North Africa is evident, from the remains of Mediterranean species of shells which are found up the mountain side in the Atlas; and it is clear the upheaval has produced the table-land out of the former sea-side plain. Many of the plains thus elevated into uplands commenced as broken ground within range of the sea, and were planed down by it during the process of fore-shore making, by what is termed marine littoral denudation. And, doubtless, many were lakes which became filled up with deposits, and then the flat surface and all beneath were uplifted during the grand, general, upward movement there, of the earth's crust. Even in the instance of those table-lands which were considered first of all—those which have been produced by the formation of deep valleys all around them—this great factor came into play, for in every instance the layers of earth or of volcanic matter which form the thickness of the land, were deposited originally flatly, and at a low level, below or not far above water-level; and, subsequently, upheaval placed them far above, and subjected them to the action of a wet climate, and rain and running water.

The occurrence of volcanic ejections or of volcanoes in and about some table-lands is almost invariable, and especially in those which are connected with the main masses of mountains. It appears as if the upheaval of such vast thicknesses of earth must diminish the pressure which subterranean substances are subjected to under other conditions. Then the internal heat of the globe could more readily fuse and develop the lava and other matters which force themselves out, with steam, through parts of the chain when there is the least resistance, and flow often over the land in a series of consecutive sheets. Table-lands thus depend for their formation, upon grand movements of elevation in the earth's crust, on denudation of the upheaved surface by air, heat, cold, rain, and rivers; and some have been fashioned more or less by volcanic overflows, and even by the planing action of the sea, when great tracts of land now raised high above, lay, it may be, as far below the level of the ocean.

The bluebell (*Campanula*), the figwort (*Scrophularia*), the grass of Parnassus (*Parnassia*), a beautiful flower, very common in bogs and swampy heaths, &c., are all good examples of plants in which the stamens are ready to discharge the pollen before the stigma is ready to receive it, and which, therefore, require the aid of insects to assist their fertilisation. But one of the most apt examples of this is exhibited by *Clerodendron Thomsonæ*—a plant originally brought from the Old Calabar River in West Africa, but now very common in our conservatories. "Four stamens, with very long filaments and an equally long, slender style, are rolled up together in the corolla bud. When this expands, the stamens straighten out nearly in the line of the tube of the corolla, and their anthers open; the style is bent so far forward as to point downwards; and the stigma is not yet ready for pollen, its own branches being united. So a butterfly, in the act of drawing

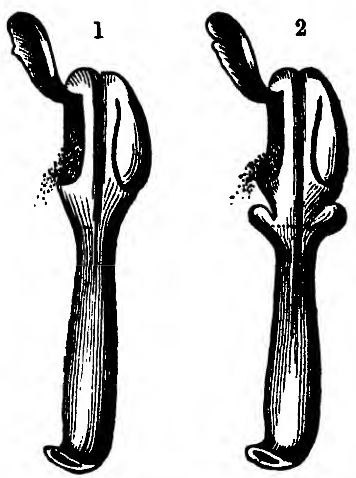


Fig. 2.—Stamens of the *Berberis* (1) and *Mahonia* (2) (much magnified).

nectar from this flower, will get the under side of its body dusted with pollen, but will not come near the reflexed or still immature style. But in a flower a day older the stamens are found to be coiled up (the opposite way from what they were in the bud), and turned down out of the way, bringing the anthers nearly where the stigma was the day before, while the style has come up to where the stamens were the day before; and its stigma, with branches outspread, is now ready for pollen—is just in position and condition for being dusted with the pollen which the butterfly has received from the anthers of an earlier blossom."*

In the common barberry (Fig. 2) a somewhat different arrangement is adopted. The bases of the stamens are extremely irritable. Accordingly, if an insect alights on them, they spring forward and strike it, the effect of this sudden movement being that the insect is dusted over with the pollen. The movement has also, as Sir John Lubbock has pointed out, in some cases the effect of startling it and driving it away, so that the humble *aide-de-camp* carries away the pollen thus acquired to another flower, without any unnecessary loss of time. The rock rose (*Helianthemum*) also shows a somewhat similar arrangement; but its history is not so marked, for the plant is almost sure to fertilise itself if insects, owing to the absence of the attraction of honey in it, fail to visit it and irritate the mobile stamens.

Kalmia (the "American laurel") is a New World genus, the waxy flowers of some species of which are familiar in our shrubberies. In this plant the anthers are contained in little pouches on the inside of the corolla, so that the ten stamens are bent all around the stigma in the form of springs. When a bee visits the flower to seek for honey, the proboscis lowers the stamen, which springs up with force, discharging, by the pores of the anther, pollen-grains, either on to the stigma or on to the insect, which flies to another flower with them, repeating the same process, and so aiding again and again in cross-fertilisation. Such is the account given by Professor Beal, of Michigan, who states that if the flowers are covered with gauze, and insects thus prevented from visiting them, no seeds set. It is thus probable that this, like many other plants—the common iris, or sedge, the "bleeding heart" (*Dielytra spectabilis*), the wild fumitory, &c., in-

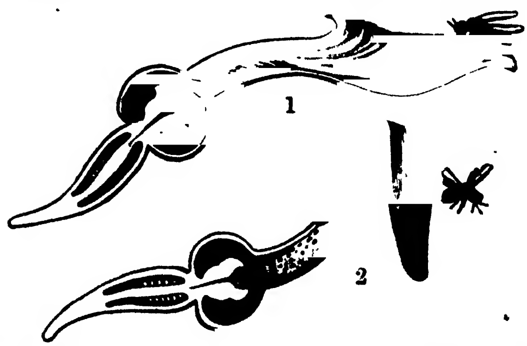


Fig. 3.—Vertical Section of two Flowers of *Aristolochia Clematis*. 1, The Young Flower before Fertilisation; 2, Older Flower after Fertilisation.

cluded—requires cross-fertilisation before impregnation can be effected.

In *Aristolochia*, or birthwort (Figs. 3 and 4), a

* Gray: "How Plants Behave," p. 22.

curious arrangement takes place. The long, contracted throat of the flower—which in America has given one of the species the common name of the "Dutchman's pipe," or pipe vine—is lined with hairs, and at the bottom expands into a chamber, where there is a broad stigma without a style, surrounded with stamens which are placed below it, but with their anthers turned away from the stigma, so that none

Fig. 4.—*Aristolochia Clematis*, showing Flies charged with Pollen Penetrating the Flower, in order to place it on the Stigma.

of the pollen can fall on it. If an insect enters, the hairs prevent it from making its escape, but as the flower advances the hairs somewhat relax, and permit of the escape of the winged messenger, laden with the pollen, which, in its struggles to get free at the bottom of the corolla, it has become covered with, and which it carries to another plant, the stigma of which is ready to receive it.

In leguminous plants, especially of the papilionaceous division, there also exists an interesting arrangement to compel cross-fertilisation. Take the common sweet-pea as an example. In this plant we find the stamens and pistils united in the form of a sort of keel, so close together that it would seem impossible to prevent some, if not all, of the pollen-grains falling on the ripe stigma. However, so important does cross-fertilisation seem to plants, that without the intervention of insects it rarely happens that a single seed is produced. The intrusion of insects causes the stamenal column to free itself from the place where it lies in the keel, and so cover the winged visitor with a cloud of pollen. Mr. Darwin has shown that bees, in visiting the flowers of the scarlet kidney bean, always alight on the left wing, and in so doing depress it. This immediately acts on the keel, which forces the pistil to protrude. On the pistil is situated a little tuft of hairs, which, by the repeated movements of the keel, brushes the pollen from the anthers on to the surface of the stigma.

Bees are necessary to the fertilisation of some kinds of clover. This fact the New Zealand Government have discovered to their great dismay, for the Dutch clover in that colony will not produce sufficient seed, owing to the absence of the particular bee necessary to fertilise it. Again, it has been found that twenty heads of Dutch clover yielded 2,290 seeds; but twenty other heads, protected from bees, yielded none. In like manner, 100 heads of red clover produced 2,700 seeds, but the same number protected from the visits of insects, were all sterile. Hence it may be logically inferred that as no other insects visit the clover, were the humble-bee to become extinct in England the plant which is dependent upon it for existence would either become extinct or at least comparatively rare. Indeed, Mr. Darwin suggests that the clover is dependent for its life on the cat. This is his line of reasoning, which in spite of now being hackneyed is still sufficiently interesting to be quoted afresh. Field mice destroy the nests and combs of the humble-bee; they in their turn are destroyed by cats—and hence the existence of the species of clover named may be said to be dependent on the number of cats in a district. This useful animal may again owe its abundance to the number of unmarried ladies of mature years, who are conventionally believed to favour its domestication!

The showy bleeding heart, which comes from Japan and China, rarely "sets" its seeds in our gardens, probably for the reason that the insect necessary as an intermediary in its fertilisation is not found in this country. The American yuccas, or "Adam's needles," are "protandrous"—that is, their stamens are ready to discharge their pollen before the stigma is ready to receive it. Hence the glutinous pollen must be conveyed to the latter organ by some other agency. This go-between is a little moth (*Pronuba yucasella*), which, according to Professor Riley, is the only insect that assists in this operation; and accordingly, in the Northern States and elsewhere, the yuccas, though cultivated for their flowers, cannot seed, on account of the

absence of the insect. The female insect only has the lower joint of the maxillary palpus wonderfully modified into a long prehensile spined tentacle. With this tentacle she collects the pollen and thrusts it into the stigmatic tube, and after having thus fertilised the flower, she consigns a few eggs bee alone, and in all the species there are interesting arrangements to permit of insects entering them and carrying off the pollen to other plants. (Figs. 5 and 6). In the common pansy there are two kinds of flowers—minute inconspicuous ones, which usually produce the seed, and

Fig. 5.—Cowslips and Violets visited by Insects.

to the young fruit, the seeds of which her larvæ feed upon. In like manner *Duvernoia adhatodoides*, a plant of the Cape of Good Hope, Mrs. Barber has shown to be fertilised by a large insect of the bee and wasp family (*Xylocopa*), which insect fertilises no other plant. Accordingly, *Duvernoia* could not in all likelihood produce seeds in this country.

The same fact is true of the pansy (*Viola tricolor*), for this plant is also visited by the humble-

showy ones, which, contrary to the case in the English species of violet, habitually produce seeds also. The inconspicuous, "cleistogenous," or "cleistogamous," flowers are always self-fertilised, and accordingly the persistency of the showy ones, Sir John Lubbock thinks, can be accounted for only by the fact that the ordinary flowers are useful in obtaining an occasional cross.

In *Viola canina* (the dog violet), an equally com-

mon species, the structure of the flower is interesting (Fig. 6). "The petals are five in number, and irregular in form, the median one being produced into a hollow spur, the entrance to which is protected by the stigma, partly by two tufts of hairs, or rather of delicate lobular processes, situated on

Fig. 6.—Vertical Section of the Flower of a Violet, with a View of the Pistil much magnified.

the two median petals. The stamens consist of a short filament, to which the anther is attached, and terminal membranous expansions, while the two lower stamens also send out each a long spur, which lies within the spur of the median petal, and secretes honey at its fleshy end. The terminal membranous expansions of the five stamens slightly overlap one another, and their points touch the pistil, so that they enclose a hollow space. The pollen differs from that of most insect-fertilised flowers in being drier and more easily detached from the anthers; consequently when the latter open the pollen drops out, and as the flower is reversed and hangs down, the pollen falls into the closed space between the pistil and the membranous termination of the stamens. The pistil is peculiar, the base of the style not being straight, as usual, but thin and bent. The stigma is the enlarged end of the pistil, and shows several small fleshy projections. It will be obvious, from the above description, that when a bee visits the flower her head will come in contact with and shake the stigma, thus opening, as it were, the box containing the pollen, and allowing it to fall on the head of the bee. It is thus carried away, and some can hardly fail to be deposited on the stigma of the next violet which the bee visits."*

But it is probably in the great family of orchids that the most curious and varied contrivances exist to prevent self-fertilisation, and to allow of insects accomplishing this as the intermediary between flower and flower. We have thirty-five species of wild orchids in Great Britain, but it is in the hot, damp forests of the Tropics that these *bizarre*-looking flowers, admired not only for their lovely forms and delicate perfume, but curious for the strange mimicry of insects and other animals which they take, attain their greatest luxuriance. Mr. Bateman, whose study of the order is as profound as his works describing them are sumptuous, remarks that flies are mimicked in *Ophrys muscifera*, bees in *O. apifera* (the only British orchid capable of self-fertilisation), drones in *O. fucifera*, spiders in *O. aranifera*. The columns of many of the Catasetums and other genera make excellent grasshoppers. Mosquitoes are borne by *Trichoceros antennifer*, or *Flor de Mosquito* of the Peruvians; dragon-flies by *Renanthera arachnites;* moths by *Phalænopsis amabalis*. Insect-like antennæ are also conspicuous in the flowers of *Restrepia antennifera*. The butterfly-plant of Trinidad is now the well-known *Oncidium Papilio*. Swans are found in the species of *Cycnoches;* doves in *Peristeria elata;* pelicans in *Cypripedium irapeanum*, which, from the great resemblance of its flowers to the bird of that name, is styled by the natives *Flor de pelicano*. The skins of the tiger and the leopard are rivalled by the petals of such plants as *Stanhopea tigrina*, *Bolbophyllum leopardinum*, &c. The *flos lyncea* of Hernandez (*Stanhopea Martiana*) is so called from its lynx-like eyes and teeth; *Dendrobium taurinum* has much of the bull about its face; and various *Catasta—C. semiapterum* especially—grin like the ugliest monkey. *Aceras anthropophora*, the man-orchis, is a well-known British plant. Even extinct animals do not always escape: a geologist would instantly recognise the head of a *Dinotherium* in the flowers of *Masdevallia infracta*. *Pleurothallis ophiocephala* has a strong resemblance to a serpent's head, and *Pholidota imbricata* an equally strong resemblance to a rattlesnake's tail. Lizards occur in *Pleurothallis saurocephala* and *Epidendrum lacertinum*, and frogs in *Epidendrum raniferum*.

The whole family comprises about 6,000 species,

* Lubbock: "British Wild Flowers in Relation to Insects," p. 60.

and of these there is perhaps not one which does not display methods more or less extraordinary to in the first place prevent self-fertilisation, and in the second to compel the insects which visit the flowers to perform this office. We shall take, almost at random, only two examples, one a British species, and the second a foreign form, premising, however, that they by no means afford exceptionally curious examples of the contrivances to which we have referred. *Orchis maculata* (Fig. 7), easily

Fig. 7.—*Orchis maculata*, showing how Bees carry on their heads Pollen-masses to the Stigma of another Flower.

distinguished from most of the order, though not from its nearest ally, *O. mascula*, by its dark spotted leaves is a common plant of meadows, pastures, and open woods. As in all the order, the pollen forms two pear-shaped masses.* When an insect visits the flower, it pushes its proboscis down the nectary, and in doing so brings the base of its proboscis in contact with the sticky basis of the "pollinia," so that when it returns it brings with it, attached to its head, the two pollen-masses. These pollen-masses, by the contraction of their bases, bend forward and downwards, so that when the insect visits another flower the "thick end of the club exactly strikes" the top of the stigma, and by the rupture of the delicate thread which unites the grains together, can fertilise several flowers, without being removed from the head of the bee. This fact of bees carrying away these pollen-masses was long known. Bee-keepers, finding their wards thus incommoded, considered it a disease —which they designated the "bee-sickness"—and it is only within a comparatively late period that the true significance of the operation has been ascertained. This description applies generally to all the British species of the genus *Orchis* (*O. pyramidalis* excepted), as well as to the man-orchid already mentioned (p. 365). In *Coryanthes macrantha*, a Trinidad species, and the only other one of the order to which our space will allow us to refer, the phenomena displayed are so strange that in order to do justice to them we shall quote the description which Dr. Crüger, who witnessed them, gave to Mr. Darwin. This botanist found the labellum, or expanded portion of the corolla, "hollowed into a great bucket, in which drops of almost pure water continually fall from two secreting horns which stand above it, and when the bucket is half full the water overflows by a spout on one side. The bare part of the labellum stands on the bucket, and is itself hollowed out into a sort of chamber with two lateral entrances; within this chamber are curious fleshy ridges. The most ingenious man, if he had not witnessed what takes place, could never have imagined what purpose all these parts serve. But Crüger saw crowds of large humble-bees visiting the gigantic flowers of this orchid, not in order to suck nectar, but to gnaw off the ridges within the chamber above the bucket. In doing this they frequently pushed each other into the bucket, and their wings being thus wetted they could not fly away, but were compelled to crawl through the passage formed by the spout or overflow. Dr. Crüger saw a 'continual procession' of bees thus crawling out of their involuntary bath. The passage is narrow, and is roofed over by the column; so that a bee, in forcing its way out, first rubs its back against the viscid stigma, then against the viscid glands of the pollen masses. The pollen masses are thus glued to the back of the bees which first happen to crawl out through the passage of a lately-expanded flower, and are thus carried away. . . . When the bee, thus provided, flies to another flower, or to the same flower a second time, and is pushed by its comrades into the bucket, and then crawls out by the passage, the pollen-masses necessarily come first in contact with the viscid stigma and adhere to it, and the flower is fertilised. Now at last we see

* "Science for All," Vol. II., p. 218, Fig. 8.

the full use of every part of the flower, of the water-secreting horns, of the bucket half full of water, which prevents the bees from flying away, and forces them to crawl out through the spout and rub against the properly-placed viscid pollen-masses and the viscid stigma." *Epipactis latifolia* —a British species — is exclusively fertilised by wasps. Hence it has not unreasonably been suggested that were wasps to become extinct in any district, so would this species of orchid. It may be added that the species with long nectaries are fertilised by moths and butterflies; those with shorter ones, as a rule, by bees and wasps.

But it is not only bees and moths that love honey and can pay for "the free lunch" by aiding in the perpetuation of the species which supplies it. Ants and other insects also visit flowers in search of it, and were there not contrivances to prevent such unbidden guests from having access to the banquet, they would soon rob the flower of its main attraction for the useful visitors. The flower is brilliantly coloured, highly scented, evidently in order to attract thither the welcome guests, while their palate is gratified by the honey which the nectaries placed in various parts of it secrete for their refreshment and in payment of their services. When it is needless to allure insects, nature has not provided any nectar—and true to the rigid economy with which she conducts her affairs, cuts off the bright petals, and suppresses the attractive odours. "Nor even," writes Dr. Ogle, "when a bait is wanted will she give it one minute sooner than necessary. The brilliancy, the scent, and the nectar are only furnished when the flower is ready for its guests and requires their presence—just as a thrifty housewife lights her candles when the first guest is at the door. The immature bud is furnished with no such attractions. Still more, even when the flower is mature, when its pollen is ready for transference or its stigma for fecundation, when all the allurements are consequently displayed and insects invited to the feast, she still shows her economy. Guests might come who were not of sufficient importance, and the banquet be wasted on them, for it is only when insects have a certain shape, size, or weight, that she requires their visits, and can use them profitably for her purposes. She requires, moreover, that they shall make their entrance by the main portal, which she has specially adapted to suit their other requirements. All insignificant and unremunerative visitors, all such, moreover, as would creep in by a back entrance, must be kept out." The treatise from which these lines are quoted is devoted to show by what various means this exclusion is effected.* Into this part of the subject, though it does not yield in interest to that which we have already discussed, we cannot, for the present at least, enter. We have, however, said enough to stimulate the curiosity of the reader. The field is extensive, and though the workers are many, they have as yet done little more than turn the sod. To the earnest student there can be no more attractive pastime, or more fertile labour. But if he can witness all the wondrous forms, and the not less wondrous physiology of the orchids, for example, without seeing in plant-life a deeper significance than even his ordinary studies of organography would lead him to, he may be very sure that he has mistaken his vocation, and had better turn to pursuits where scientific curiosity and reverential wonder in no way add to the amenity of his daily life.

A CUTTLEFISH.

By Dr. Andrew Wilson, F.R.S.E.

THE most natural query with which one may begin the study of a cuttlefish is the question "What is it?" To fairly answer this question may be described as the chief intent of the present paper; but it may be possible to indicate first generally the zoological standing of the cuttlefishes, if only by way of delineating the main outlines of their history, and of thus once for all settling their status as animals of comparatively high rank. The brief examination of any cuttlefish would, for instance, show that the skin, or covering of its body, is most nearly represented by that layer or membrane which, on opening a mussel or oyster, we find lining the shell, or which is seen occupying a similar position in a whelk, snail, or other "shell-fish." Moreover, we find that cuttlefishes may

* Kerner: "Flowers and their Unbidden Guests" [Ogle] (1878); Darwin: "Fertilisation of Orchids" (1868); Müller: "Blumen u. blumen besuchende Insekten" (1870); and "Die Befruchtung de Blumen durch Insekten" (1873).

with all justice participate in the latter name, inasmuch as they possess "shells"—not always recognisable as "shells" of ordinary type, it is true, but which are nevertheless strictly of the nature of these structures. The shells are further formed in cuttlefishes, as in other molluscs, by the membrane lining the shell, and which is named the "mantle." Now, here are two characters which entitle cuttlefishes to be regarded as belonging to the "shell-fish" group of animals. And were the general anatomy of cuttlefishes to be further discussed, other points of likeness to the ordinary "shell-fish" — points of resemblance often concealed beneath special and peculiar modifications of structure—would be readily found.

We may thus take for granted, at the commencement of our study, that cuttlefishes are simply peculiar "shell-fish." To use the zoologist's method of placing this fact before his readers, we might say that cuttlefishes belong to the type *Mollusca*—a declaration which means much the same thing as saying that they are far-off cousins of the oysters, whelks, mussels, and other and less familiar animals. Notwithstanding this, it may seem at first sight difficult to reconcile the exact idea of ordinary shell-fish structure with that of the cuttlefishes; but in a simple fashion, nevertheless, their correspondence may be traced. The figure and form of a snail (or whelk) crawling along upon the great broad muscular disc named the "foot" (Fig. 1, B, F), are familiar to all. The head of the snail is distinctly perceptible; its body (*b*) (as distinguished from the head) admits of easy recognition; and the upper and lower surfaces of the mollusc's body are plainly discernible. There is, therefore, no special difficulty of any kind in understanding the general form and disposition of a snail's anatomy. Now if we trace the development and growth of snail or whelk, or any other member of the whelk's class (*Gasteropoda*), we shall find that this "foot" is a most important structure in producing the characteristic conformation of the body of these animals. It begins as a small process placed below the mouth and head. Then, as growth advances, it develops itself behind the head and mouth, growing away from the mouth, so to speak, until it becomes the broad walking surface of the mollusc. Thus the broad under-surface of the snail's body, as well as its elongated shape, are the results of the growth of its "foot." Now, cuttlefish existence begins much in the same fashion as does snail or whelk life. If we suppose that the "foot" in a cuttlefish remains in its original and early position below the head (Fig. 1, C, F), and that the subsequent growth tends to increase its body (*b*), not in length, as in the snail, but in height, we shall gain a true idea of the reason why a cuttlefish, whilst related to the snail, is yet unlike that animal. The cuttlefish, in a word, grows upwards; the snail-body grows lengthwise. The former has a foot which extends backwards; the latter has a foot which exhibits no such extension, though, indeed, it attains a much more characteristic form and development than in the whelk-class.

To understand the form and outward features of a cuttlefish, therefore, we must place it in a position which will truly represent its relationship with its more familiar relations the snails and whelks. The animal must be placed, therefore, head downwards (Fig. 1, C), with the arms and tentacles which encircle its head lowest. The reason for such an apparent inversion of cuttlefish structure becomes clear, when we find that these arms or tentacles (F) really represent

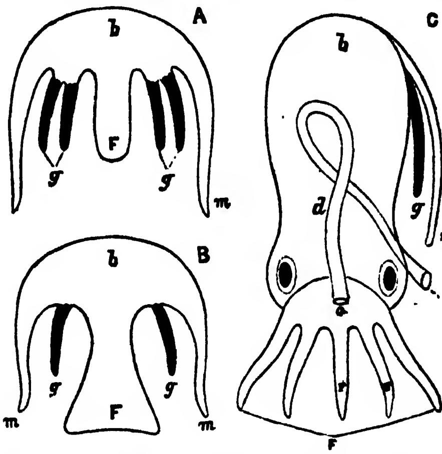


Fig. 1.
(A) Cross Section of Mussel, or Lamellibranchiata: (B) Cross Section of Gasteropod; (C) Cross Section of Cuttlefish; (*b*) body; (*g*) gills; (F) foot (*m*) mantle; (*o*) mouth; (*d*) digestive system.

the "foot" of the snail, and that, therefore, "head-downwards" is the zoological position of the cuttlefish in descriptive anatomy. Too frequently these animals are described in books as if their natural aspect—namely, head upwards—corresponded with the structural plan of their bodies. A cuttlefish, then, we repeat, is simply a snail-like animal, with foot split into separate pieces or "arms;" the foot having grown over the mouth (*o*), and the body (*b*) having developed upwards instead of lengthwise. Modifications of "foot" and "body" produce all the characteristic forms we see in molluscous animals but perhaps the cuttlefishes carry off the palm in respect of the curious development which has

produced organisms so weird and curious as are the subjects of our present study.

That study may be continued most satisfactorily by the investigation of the head-extremity of the cuttlefish in the first instance. Here, the development of this all-important region attains its fullest limits in the molluscan type. Bearing a pair of very large eyes on its sides, and having the mouth in the centre of its crown, the head of the cuttlefish gives character to the whole frame. The arms or tentacles, which we have just noted, correspond to the "foot" of the snail, surround the mouth, and vary in number in different cuttles. In only one cuttlefish — the pearly nautilus — do the arms number more than ten; and it may be well to remark in passing, that as this latter cuttlefish stands alone and peculiar in many respects as the last survivor of a long line of ancestors, we may profitably for the present omit all reference to its structure. These remarks, applying to all other cuttlefishes, therefore, lead us to note ten arms as the greater, and eight as the lesser number of these possessions. Where we find ten of these appendages, as in the sepias and squids, two are placed outside and are larger than the others. In that case, also, whilst the eight arms of uniform length possess suckers over their inner surfaces, the two elongated ones possess suckers at their tips only. The suckers, or "acetabula" (Fig. 2), as they are named, are deserving of close study. Each sucker consists of a cup bounded by a horny ring, which, as in the squids, may be cut to form a series of minute sharp hooks. Indeed, the development of

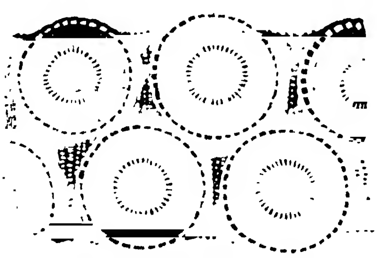


Fig. 2.—Suckers of Cuttlefish.

hooks appears in some of these beings—the so-called "hooked squids"—to supersede the suckers; and these latter forms are able to extend and retract the hooks of their arms very much as a cat is able to protrude and sheathe its claws. In the ordinary sucker, however, we find a perfect apparatus for producing an instantaneous vacuum, and for thus utilising the pressure of the outside water or air for securing a firm hold of the prey or other object. A muscular plug or piston exists within each sucker, the withdrawal of this piston producing a vacuum, whilst the vacuum can be destroyed and the sucker released by the protrusion or descent of the plug. The principle involved is, in fact, that which regulates the working of the schoolboy's "sucker." And when we consider that the cuttlefish possesses several hundreds of these suckers, and that their adhesion can

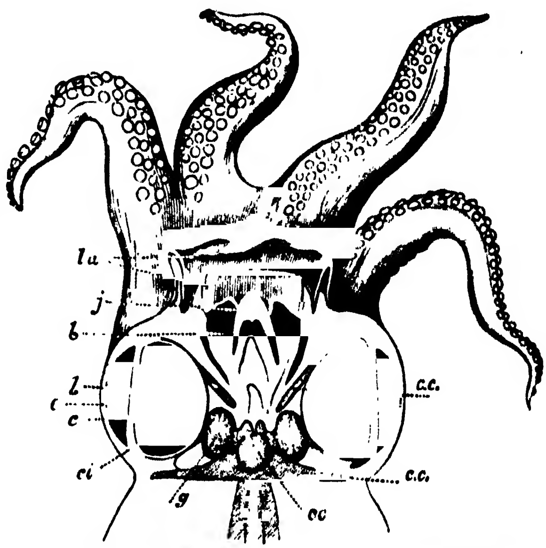


Fig. 3.—Section of Head and Jaws of Cuttlefish, showing Nervous Mass and "Skull."

(ce) Cerebrum; (g) Ganglion of the Optic Nerve; (c c) Cephalic Cartilage; (l a) External and Internal Labial Membrane; (j) (Jaws); (b) Buccal Mass; (l) Lens; (c) Eyelid; (c) Cornea; (ci) Ciliary Body.

be effectively and instantaneously secured, it can readily be imagined that the grasp of the cuttle is of no ordinary or weakly kind. Any one who has watched the apparently light touch with which the crab-prey in an aquarium has been quickly seized and conveyed to the mouth by the extended arm of a cuttlefish, or who has observed the aquatic antics of an eledone (Fig. 6) using its arms in every conceivable fashion as a means of attachment, will have realised the dexterity of manipulation in these creatures.

But the head of the cuttlefish (Fig. 3) offers structures of even greater interest than the arms for examination. Such are the mouth and its armature, the "brain," "eyes," and other organs of sense. The furnishings of the mouth of these animals include a set of powerful "jaws," and a peculiar organ, not confined to the cuttlefishes, but represented in the snails and whelks likewise, and called the "tongue," or *odontophore* (Fig. 4). The jaws of a

cuttlefish must not be confounded or compared with the jaws of higher or vertebrate animals, for the plain reason that they are organs of widely different nature. Thus the cuttlefish "jaws" are simply hardened developments of the lining membrane of the mouth, and not, as in higher animals, definite parts of the head. The "jaws" of molluscs, in fact, more nearly correspond to our teeth than to our jaws. In the cuttlefishes, these organs are of a horny nature, and bear a close resemblance to the beaks of parrots. They are arranged in two sets, one in front and one behind, and the shorter or front jaw works into the larger, so as to divide and tear whatever substances are submitted to their grasp. An inspection of these jaws and of the powerful muscles by which they are moved, readily shows how the hard shells of crabs and other crustaceans are broken down and masticated by the cuttlefishes. In addition to these jaws, we find in the mouth a peculiar rasping apparatus, called the *radula*. This consists of an arrangement of horny teeth set in a special part of the cavity of the mouth, and moved by special muscles, so that the food is thoroughly triturated and divided. As the teeth of the radula are worn away by the friction involved in their work, they are replaced by fresh tooth-growths from behind. A soft "organ," which receives the name of "tongue," is also to be included in the list of the furnishings of the cuttlefish-mouth.

Fig. 4.—Teeth of Odontophore of Cuttlefish.

Perhaps the most interesting part of cuttlefish anatomy is that which refers to the form and structure of the chief nervous mass (Fig. 3, *ce*) of the body. That this mass should be found to be situated in the head is matter of no surprise. The large size of the head of these animals (and in the snails and whelks class as well) is possibly as much due to the concentration of the nerves in this region as to any other feature or condition of growth and development. But that which most interests us in the nervous centres of the cuttlefishes is the fact that, like the chief nervous centres of vertebrate animals, they are enclosed in a gristly or cartilaginous box that forms a kind of protective case or "skull." This box, named by zoologists the "cephalic cartilage" (Fig. 3, *cc*), also serves as a point of attachment for many important muscles of the cuttlefish-frame. It might at first sight be thought that the presence of this internal head-case would form evidence of relationship between the cuttlefishes and the higher or vertebrate animals. But we must be careful to avoid making any such comparison. On no theory whatever is there any connection, direct or indirect, to be traced between vertebrates and cuttlefishes. The presence of a gristly case for the protection of the nerve-centres, or for a support of the head and for muscular attachments, is a fact which simply illustrates that principle of nature whereby we frequently find allied structures developed in widely different animals. It seems most reasonable, indeed, to conclude that the "skull" of the cuttlefish has been provided to meet laws and conditions acting on these animals independently of the conditions which affect any other group of beings. As Mr. Darwin has himself remarked, "It is a common rule throughout nature that the same end should be gained, even sometimes in the case of closely related beings, by the most diversified means;" and again, "As two men have sometimes independently hit on the same invention, so natural selection, working for the good of each being, and taking advantage of all favourable variations, has produced similar organs, as far as function is concerned, in distinct organic beings, which owe none of their structure in common to inheritance from a common progenitor."

In a snail or whelk we find three chief nervous masses, connected by nerve-cords, to form the nervous system. These three masses are placed, when typically arranged, as follows:—one in the head, one in the foot, and one in the neighbourhood of heart and gills. Now, in the cuttlefishes, we find that, instead of the nervous centres being thus scattered over the body, nature has concentrated and localised the nervous system in the head, thereby gaining additional nervous power without violent departure from the original type of the molluscan nervous system at large. The same principle of concentrating nerves, and of thereby gaining additional nervous power, is well seen in the difference between the nervous systems of worms, insects, and spiders—animals constructed upon the same (Articulate) type, just as whelks, snails, and cuttlefishes belong to one and the same (Molluscan) type or plan. A worm's nervous axis consists of a double chain of nerves; in the higher insect this double chain has become single by fusion of its originally separate parts; whilst in the spider the chain-like form of the nervous system is barely recognisable, since, with the requirements of more complex instincts, the

nerve-chain has become moulded and modified to form a great central mass, whence spider-life derives its noted cunning and dexterity. It is interesting to observe that in the chief nervous mass of a cuttlefish we are able to recognise those elements of grey and white nervous matter with which we are familiar in the brain and spinal cord of vertebrate animals. This latter feature forms another illustration of that principle of the independent origin of similar structures already illustrated by the presence of the cuttlefish "skull." And the consideration of the nervous axis of these animals has therefore taught us the important lessons—first, that nature produces new effects in animal life by the modification of an original type, and not by the creation of absolutely new parts; and, secondly, that the development of widely different animals may often run, independently, in marvellously similar grooves.

With organs of sense, our cuttlefishes are well supplied. The wary, active life of these animals, as exhibited in an aquarium, is carried on through the possession of "gateways of knowledge" of very perfect kind. Curiously enough, whilst likeness between the "skull" of a cuttlefish and that of a vertebrate might be argued for—although erroneously as we have seen—a similar but equally mistaken resemblance was actually insisted upon as existing between the eye of a cuttlefish and that of higher animals. The description of either eye would occupy too great a space, and deal with matters of too technical a nature, for the present paper. Suffice it to say that the "lens" of the cuttlefish eye (Fig. 3, *l*) is really a double structure, like the "Coddington lens" of opticians, and not single, as in the back-boned animal's organ of vision. Moreover, the nervous network, or *retina*, of the cuttlefish is inverted, if we compare it with the similar structure of the eye of the vertebrate creature; and, whilst a large nervous mass actually exists within the cuttlefish-eye, such an arrangement is not present in the eyes of higher animals. That the cuttlefishes possess "ears" is a matter concerning which the popular observer, who is accustomed to regard outer ears as the evidence of the possession of organs of hearing, might perchance be doubtful. But the slightest reflection would convince us that in many higher animals perfect hearing powers exist in the complete absence of outer ears—*e.g.*, fishes, frogs, birds, seals, whales, &c.—whilst the most elementary knowledge of physiology would convince us that that which is the essential part of an ear is placed *inside* an animal's head, and not externally. But we might go further still, and assert that powers of hearing may exist in the absence of any definite organs of hearing whatever. Insects hear; yet in only a very few of these animals have hearing-organs been discovered; and we may in such a case fairly assume that in the beginnings of a sense, as in the first developments of other things, a function may be performed by a general surface or organ, and only later in its history become represented by a special apparatus.

The beginnings of ears in the animal world probably exist in the jelly-fishes. Around the margin of their delicate bells, we find little sacs or bags, containing fluid, and having suspended in the fluid minute particles of limy matter. Such an apparatus is well calculated to receive simple sound-waves, and to transmit these vibrations to the body. What a jelly-fish "hears" it is impossible to say. The "hearing ear" of higher life is really the product of the "understanding brain" —for hearing and seeing, like most other acts of life, are really brain-acts, and not those of the organs of sense. It is interesting to observe how the simple type of hearing organs observed in a jelly-fish is, with comparatively little elaboration, preserved to us in the ears of molluscs, and in those of the cuttlefishes amongst these animals. The "auditory sacs," or hearing bags or "ears," of the cuttlefishes are enclosed in little depressions of the gristly "skull," each containing a single limy particle or "otolith" ("ear-stone"). In many cuttlefishes a minute canal is traceable from the ear to the body-surface; but whether this is to be regarded as a canal placing the internal ear in communication with the outer world as in ourselves, or as a feature resulting from ear-development, and not from ear-function, is matter of discussion. The first of these alternatives seems, however, by no means an unlikely theory. It is needless to remark that the cuttlefish "ear" receives a special nerve—that of hearing—whose fibres end in a special "plate," adapted to receive, through its fine hairs, the vibrations of sound. That the cuttlefishes, like the vultures, can "scent the prey from afar," is matter of common observation. Hence the conclusion that they possess organs of smell is a most natural inference. The "nostrils," if by courtesy one may so term the olfactory regions in these molluscs—exist in the form of fine pits—usually placed behind the eyes—or of little projections or *papillæ*. These receive the ends of nerves which from their structure and relationship are known to exercise the sense of

smell. The sense of taste is exercised by the "tongue," and probably by the soft parts of the mouth likewise; and the tentacles or "arms" are efficient organs of touch, whilst, indeed, the whole body-surface is endowed with a high sensibility.

Such sensitiveness is manifested in the cuttlefishes in a highly interesting fashion. No feature of their existence has called for more special remark, perhaps, than the extraordinary play of colour which their bodies exhibit. If the reader falls in with a Squid, or *Loligo*, which has just been stranded on the sand, and touches the body, he will be a witness to the grandeur of the "expiring agonies" of the mollusc. Every touch causes angry blushes of deep crimson, shading off to a light purple hue, to shoot across the body, and when unduly irritated the play of colours becomes still more intense. Even the Octopi of our aquaria, which in their more sombre tints can hardly rival the loligos of our coasts, exhibit the same curious phenomena of colour-changes. And it would thus seem that cuttlefish sensibility, like that of the highest animals, is manifested through phenomena of similar description. The mental phenomena of man are often discernible through the alterations of colour, as the traits of cuttlefish character, in a rude way, are manifested through their power of "blushing," and that in a most vivid manner. The play of colour in a cuttlefish is effected in a manner readily understood. Imbedded in the under skin, and clearly visible through the thin and transparent outer skin, are a large number of cells, loaded with pigment, and named *chromatophores*. These cells are provided with special muscles, through the action of which their form can be instantaneously and greatly altered. When contracted and at rest, the cells appear merely as dark specks; but under stimulation they become greatly elongated and extended; their pigment contents become apparent; and the "shot" colours are thus produced.

The complexities of organisation which have already met us in our study of the cuttlefishes warrant us in expecting that the ordinary systems of organs, proper to the bodies of animals at large, will be fully represented in these molluscs. Such expectation would be fully realised by our discovery that in the matter of digestive apparatus, heart and blood-vessels, and breathing-organs, a cuttlefish is on a par with most true fishes, and greatly ahead of many members of that vertebrate group. A gullet (Fig. 5, *f*), stomach (*h*), and intestine (*i*) are always present, and form the main line of the digestive system, as in ourselves. In some cuttles (as in the Octopus) we find a bird-like "crop," and the stomach itself may be very muscular for its size. Such features bespeak a very varied "commissariat" on the part of their possessors, and what is known of the rapacity of cuttlefishes fully justifies this latter inference.

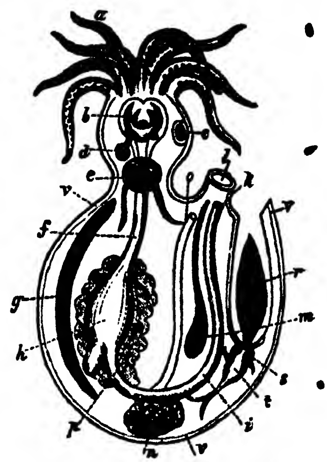


Fig. 5.—Diagram of Structure of Cuttlefish.

(*a*) Tentacles; (*b*) Buccal, or Masticatory Apparatus; (*c*) Eye; (*e*) Nervous Ganglia; (*g*) Internal Shell; (*k*) Anus; (*n*) Ovary; (*o*) Oviduct; (*s*) Branchial Heart; (*t*) "Systemic" Heart; (*r v v*) Mantle.

The "glands" of the digestive system are also well represented. There is always a large liver (Fig. 5, *p*), affording bile for the digestion of the food, and salivary glands (*d*) also exist, and pour their secretion into the throat. A peculiar sac or bag, the "ink sac" (*m*), may also be reckoned among the belongings of the digestive system of these animals. Opening by a duct which leads into the "funnel" (to be presently noted), this "ink sac" secretes a dark fluid, readily soluble in water. Hence, when hotly pursued, the cuttlefish, squirting its ink into the surrounding water, escapes from its enemies under cover of a literal "cloak of darkness." The justice of the simile which compares a verbose controversialist to a species of human cuttlefish, may, after the foregoing statement, be perfectly comprehended.

The cuttlefish possesses a well-developed heart, which acts, as does our own, as the central pumping-engine of the circulation, although it differs from the heart of man in that it only drives pure blood through the body, and does not (as in man) send impure blood to the breathing organs for purification likewise. The process of blood purification, or "excretion," as it is named, is performed in higher animals by the lungs, skin, and kidneys. The cuttlefishes possess organs which represent the kidneys of other animals; and as the lungs of man are represented in water-living animals by the "gills," we accordingly find that the cuttlefishes possess two gills (*r*), one on each side of the body. These gills are plume-like organs, which, like every other gill (or lung), consist essentially of dense networks of blood-vessels. In these organs the blood is exposed to the action of the oxgyen of the sea water taken into the gill-chamber, and gives off the

Fig. 6.—Eledone Moschata, one of the Eight-armed Cuttlefishes, allied to the Octopus.

carbonic acid gas and other waste products of the body's work.

A cuttlefish, resting in its tank at an aquarium is seen to breathe incessantly, with a regular movement of body. Careful observation shows us that at each "inspiration," when the body expands, water is drawn into the gills through special openings or clefts situated in the "neck" of the animal, and just below the head. These apertures can be closed by valves; hence, when the animal expires or contracts its body, the openings of entrance are closed, and the effete water (now robbed of its oxygen and loaded with waste matters) is forcibly driven out by a tube opening at the neck, and named the "funnel" (Fig. 5, *l*). This funnel opens on the hinder face of the body, and when the animal is at rest serves, as just remarked, to convey the effete water of respiration out of the body. When, on the contrary, cuttlefish-activity is called into play, these *jets d'eau* serve the purpose of a hydraulic engine. Forcibly expelled from the funnel, the moving jets of water, striking against the still and inert body of water around, drive the animal swiftly backwards in the sea. The graceful aqueous flight of a cuttlefish is thus readily explained, as the result of propulsion by water-power.

Reference was made at the commencement of this paper to the "shell" of cuttlefishes. Only two of these animals possess a "shell" which could be recognised as such by the non-zoological observer; these being the pearly nautilus (Fig. 7), with its large chambered shell, and the paper nautilus (Fig. 8), with its light papery apology for that structure.

Fig. 7.—Section of Pearly Nautilus.

Other cuttlefishes possess "shells" in the form of horny or limy structures, situated within the "mantle," or investing skin of their bodies. This "shell" varies in the perfection of its structure. In the Squids it is a mere horny pen; in the Sepias it exists as a limy plate; in the little *Spirula* it is a chambered structure; and in the exinct *Belemnites* it was also internal, and chambered likewise. One interesting fact concerning the "shells" of these animals may be mentioned by way of close to their history, in the shape of the remark, that in all probability we must consider horny and limy internal "shells" of living cuttles as rudiments of shells once better developed in past ages of the earth's history, and in cuttlefish races of "the long ago."

Fig. 8.—Paper Nautilus.

The pearly nautilus was mentioned at the beginning of this paper as a cuttlefish which, like "the last of the Mohicans," was the sole survivor of a long and remarkable line of ancestors. Now, nautilus-like or four-gilled cuttlefishes, with chambered shells, were unquestionably the earliest of the race to appear in earth's seas. This much is positively known from the history of fossils. Ages before any of the soft-bodied two-gilled cuttles appeared, Silurian, Devonian, and Carboniferous seas* swarmed with the four-gilled forms of which the names are "writ large" in the primers of geology. Only when the middle-life period of geology—which began with the Triassic Rocks—was ushered in, do we find the first traces of the existence of two-gilled cuttles in the internal shells of the Belemnites. Henceforward, and from the Trias, the two-gilled races seem to have flourished along "the files of time," whilst the four-gilled and shelled forms of cuttlefishes began to dwindle in numbers, and slowly to disappear. True, the Ammonites form a splendid series of shelled forms in Trias, Oolite, and Chalk; but at the close of the latter period, they vanish altogether from the fossil record, and leave the Nautili to represent in themselves the cuttlefish life of Palæozoic æons. Meanwhile, the two-gilled cuttles flourish and survive. The Belemnites, which possessed elaborate internal shells, and which ushered in the two-gilled race, disappear with the close of the Chalk Epoch, leaving to the succeeding Sepias, Octopi, Loligos, Argonauts, &c., the future representation of cuttlefish interests in the great world of life.

Thus the four-gilled cuttlefishes are probably the remote ancestors of the two-gilled and existing

* See Frontispiece to Vol. I. for section showing the relative positions of these rocks.

forms. It is noteworthy to observe, last of all, that the two-gilled race, not merely in numbers, but in size, bids fair in our day to rival the developments of the past. Victor Hugo's "devil-fish" has, in reality, its true representatives in our oceans of to-day. Huge cuttlefishes have been met with over and over again within the past ten or fifteen years. One specimen driven on the Irish coast—a kind of large squid—possessed an elongated tentacle which measured thirty feet in length. Professor Verrill, of America, has placed on record a large number of instances of the occurrence of giant cuttlefishes off the coasts of the United States. One of these was stranded on November 2nd, 1878, near Notre Dame Bay. Its body measured twenty feet long, from mouth to tail, and one of the tentacles measured thirty-five feet. Thus, to the interest which a complex organisation and a singular past history together present, and to that which a curious and weird appearance may engender, the cuttlefishes unite the interest derived from a consideration of the huge and monstrous in size—a combination of qualities which may more than justify the further pursuit of zoological knowledge, and a more intimate acquaintance with the scientific lore of the modern "Krakens," and their humbler fellows, the Squids and Octopi of our own seas.

HOW LIGHTNING IS KINDLED IN THE THUNDERSTORM.

By Robert James Mann, M.D., F.R.C.S., F.R.A.S., etc.

THE observations of meteorologists show that the vapour which ascends in an invisible state from the ground carries with it, in calm and fine weather, into the higher regions of the air, a very considerable supply of positive electricity.* Each minute vapour-particle that goes up bears its own portion of the load. When, however, the invisible vapour has thus mounted into very high regions of the air, it loses its invisibility, and is condensed into visible mist, as has already been explained in detail.† Numerous particles of the aqueous substance are drawn close together, and grouped into the form of little vesicles or globules. Each one of these is then a reservoir or receptacle of electric force, and as more and more watery vesicles are condensed more and more electricity is collected in the gathering mist; but each of the water-globules is still enveloped by a space of clear air. In a drifting cloud the mist-specks can be discerned floating along with transparent intervals between. The clear air which lies around the globules of vapour then acts as an insulating investment; it imprisons its own part of the acquired electrical force in each separate globule. The cloud is thus not charged as a whole, like a continuous mass of metal, with its electricity spread upon its outer surface. It is inter-penetrated everywhere with the force. It is composed of a myriad of electrified specks, each having its own particular share of the electric force, and each acting as a centre of electrical energy on its own account. The electricity which at any one instant resides in the outer surface of a cloud is, therefore, but a comparatively small portion of that which is present in the entire vaporous mass. That such is the way in which electricity is stored in the clouds has been proved by direct observation. When a gold-leaf electrometer is placed in the midst of a cloud driven along by the wind, it is seen that the strips of gold-leaf continually diverge and collapse as the mass of the cloud passes along. There is an electrical charge acting in all parts, but the charge varies in intensity from place to place accordingly as there is a greater or less condensation of the particles of vapour in each particular spot. But the influence externally exerted by the cloud is nevertheless capable of being raised to a very intense degree, because it is, so to speak, the sum total or outcome of the force contained in the innumerable internal centres of energy. It is no uncommon thing for the electrical force emanating from a cloud to make itself felt in attractions and repulsions many miles away. Clouds resting upon the remote horizon thus frequently produce perceptible effects at distances from which the clouds themselves cannot be seen. An electrical cloud hanging a mile above the ground acts inductively upon that ground with considerable power.

When in summer-time the temperature of the earth's surface is very high, the ground moist, the air calm, and the sky clear, very copious supplies

* "Science for All," Vol. III., p. 333.
† "Science for All," Vol. III., p. 31.

of vapour are steamed up from the ground under the hot sunshine. Clouds, however, begin at length to gather in elevated regions of the air out of the abundance of the supply. The free electricity which has been carried up with the vapour is at first pretty evenly spread through the clouds; but after a time, as the electrical charge becomes more and more intense, a powerful repulsive force is in the end established between the spherules of the mist, and a very high degree of tension is at last produced at the outer surface of the cloud, where it is enveloped by insulating air, until in the end the expansive energy there becomes strong enough to occasion an outburst from the cloud. The escape of the redundant charge then appears to an observer's eye as a flash of lightning issuing from the cloud. Such, in its simplest form, is the way in which lightning is kindled in the storm-cloud.

When a dense and electrically-charged cloud floats in the air over the ground, if the charge consists of the positive electricity which is ordinarily supplied to the air, that reacts inductively on the ground, and calls up in it a very vigorous tension of an opposite or negative kind immediately beneath. The positive cloud and the negative earth both act each upon each, and as the electrical states in the earth and the cloud are of an opposite kind, it is attraction which ensues; but as the solid ground is a fixed mass, whilst the cloud is a floating and movable body, the cloud immediately begins to descend towards the earth. As it does this, two things occur. First, the electrical tension of both the cloud and the earth increases as the distance between them grows less; and then, as this distance grows less, the insulating chasm exerts less and less imprisoning or restrictive power. There therefore occurs in the end a time when the electrical charge of the cloud can no longer be kept in by the air, and a discharge then occurs; but that discharge is of a *double* character. A portion of the redundant positive force which was imprisoned in the cloud leaps to the earth, and a portion of the negative force which was inductively concentrated beneath escapes to the cloud. So much of the redundant force of both the cloud and ground is neutralised by the mingling of the two; but the cloud is not in consequence exhausted of its charge. When the outburst of its redundant superficial energy occurs, the loss which is entailed at its outer part is quickly repaid by the transference of a fresh supply from the inner stores of the aggregated vapour. Thus many discharges of lightning take place as the cloud is drawn towards the earth before its accumulated store is finally exhausted. When positively-charged thunder-clouds hang over the negatively-charged earth, the flashing of the lightning is between the earth and the cloud.

But although the clouds are thus ordinarily charged with positive electricity, like that which is a natural attribute of the air in fine weather, such is not always the case. The vapour which ascends quietly from large spaces of water like oceans and seas is the great source of the normal positive charge. But it occasionally happens, from some local cause of reversal of the ordinary state, that negative force is developed in limited spaces of the moist ground in such excessive abundance that it quite overcomes the natural positive charge of the superincumbent air. It is a negative charge which is then carried up with the vapour into the clouds. But when this occurs there are usually positively charged clouds floating high in the air, which have received their electrical store from the wide ocean-covered spaces of the earth, and the negatively-charged clouds get to be interposed between those high ones and the ground. In such circumstances the oppositely-charged clouds exert upon each other an attractive force, and get nearer together. The lightning then at last flashes from cloud to cloud. In all other particulars, however, the process is precisely the same as when the discharge is between the clouds and earth, and the lightning continues flash after flash, until both sets of clouds are exhausted of their antagonistic energies. Very complicated conditions indeed are in such cases apt to be produced when there is great electrical disturbance prevailing in the air. Heavy rain carries down large quantities of positive electricity, and in that way materially diminishes the negative excitement of the ground. It not uncommonly happens that positive electricity is indicated by instruments during the fall of heavy rain, and that negative electricity appears as the rain drifts away. The positively-charged rain-clouds seem to be enveloped by a rainless space, which is negatively electrified by induction. When many isolated showers are falling simultaneously at short distances apart, there are thus numerous tracts of positively and negatively electrified space scattered side by side. During a residence of six days upon the summit of the Faulhorn Mountain, in Switzerland, during which there were frequent falls of snow and sleet, M. Peltier observed that when the snow came from white clouds it was invariably positively electrified, but that when sleet

fell from dark clouds it was as constantly negatively charged.

When a thunder-cloud is in process of formation numerous small cloudlets are seen to be piled rapidly together, and the gathering mass is extended towards the horizon until it seems to rest upon the earth by a broad flat base. This soon assumes a dark threatening aspect, and the lowering darkness rises gradually up into the masses above, from which, at the same time, long streamers stretch out and get interwoven together until they ultimately cover the entire sky. Isolated cloud-wisps simultaneously appear amongst the streamers, and hurry confusedly and fitfully about. These flitting attendants of the gathering storm are distinguished by some meteorologists by a particular name—they are called *ascitizi*,* and are held to be special indications of the electrical character of the disturbance. The general mass, which is more or less homogeneous and level below, is ruggedly broken above into lofty projections and deep cavities. These storm-clouds move to some extent in the general current of the wind, but they are also driven confusedly about in all directions by the attractions and repulsions of the electrical force.

Although the prominent features of the formation of thunder-clouds can be thus definitely described, the most perplexing complications are continually worked out by the perturbing agency of induction. Clouds negatively charged are piled up in one place, clouds positively charged are collected a little distance away, and other clouds in which the electrical disturbance is, in the first instance, slight, are soon brought into the most energetically perturbed state with concentrations of negative energy at one place, and of positive energy at another. In this way broad and deep stretches of the atmosphere at last get involved in the conflict, and become seamed in all directions with the readjusting lightnings.

The connection of thunderstorms with ascending currents of hot moist air is in some instances very clearly marked. The summits of the mountains above Port Royal, in the island of Jamaica, become covered with clouds day after day about the hour of noon. These acquire their greatest density within an hour afterwards, and rain is then poured out of them, with almost unceasing discharges of lightning until towards three in the afternoon, when the storm is brought to an end, the sky clears, and fine weather returns. This happens every day during the rainy season, a period extending over five months of the year. One hundred and fifty thunderstorms occur usually at Kingston within that time. The periodic return of these storms, so regularly immediately after the hottest hours of the day, is quite manifestly due to the upcast of the heated and moisture-laden air then established along the ascending slopes of the mountains.

A somewhat similar periodicity in the recurrence of thunderstorms is observed along the rising seaboard of South-eastern Africa, and is especially marked in the colony of Natal. The land there rises in abrupt slopes from the margin of the Indian Ocean, until at a distance of 120 miles from the sea it has attained an elevation of 6,000 feet. Up this slope a moist warm sea wind blows from the ocean, almost continuously during the hottest season of the year, being obviously a direct upcast established by the heating of the air over the land. The day generally begins with a clear sky and burning sunshine. But towards noon the sky becomes overcast with clouds, which first appear in the higher regions of the mountains, and then extend downwards along the lower slopes. About a couple of hours after noon, rain falls from the thickening clouds, and all the conditions of a violent thunderstorm are developed. This happens somewhere along the extended stretch of coast pretty well every day during the summer season, which runs from October to February. The storms recur at the same hour day after day, and appear over any one particular spot four or five days in succession. At Pietermaritzburg, the capital of Natal, which stands fifty miles in from the sea, and at an elevation of a little more than 2,000 feet, there are habitually from fifty to sixty afternoon thunderstorms during these hot months. A dense mist continues to envelop the sky after the heaviest rainfall until far on into the night, and then suddenly the cloud-curtain is drawn aside, and the sky scintillates all over with stars that are too faint to be seen by the unaided eye under less favourable circumstances. At times, in the small hours of the night, the entire canopy of the heavens looks as if it were converted into one continuous Milky Way by the scattered star-dust, excepting in the "coal-black" blank spaces neighbouring the Southern Pole. Even the thunderstorms of England can frequently be traced to a powerful upcast of hot moist air, produced by the long continuance of a clear sky and hot sunshine, and they are then apt to recur at the same hour of the day until the

* Ascitizi, allied or associated clouds; from the Latin *ascisco*, to associate.

atmospheric conditions are changed. But thunderstorms are quite as frequently produced in England by the less regular influence marked by the conflict of opposing winds. The sudden and copious deposition of vapour, and the formation of electrically-charged clouds, are then due to the mingling of large volumes of hot moist air with a chill current drifting in from drier and colder parts of the earth. Thunderstorms occasionally occur in very elevated regions of the air. Both Humboldt and De Saussure observed thunderstorms in mountainous regions which were more than 16,000 feet above the sea. M. Arago has also left it upon record that he had noticed storm-clouds at scarcely inferior altitudes over low countries and broadly extended plains. The heaviest storms, however, are for the most part experienced somewhere between 600 and 6,000 feet above the ground. But in such cases vast depths of the air are generally involved in the electrical disturbance, and traversed by the lightning.

Twenty years before the experiments of Stephen Gray, cracklings of sound and flashes of light had been produced by rubbing amber with wool by an earlier experimenter, Dr. Wall, who described his proceedings in a paper communicated to the "Philosophical Transactions" in 1708, and in doing so used the memorable expression that it seemed to him the crackling and light were very much like thunder and lightning. Stephen Gray, in speaking of the electrical spark in 1729, still more forcibly dwelt upon this resemblance. "Though these effects," he remarks in a remarkable memoir,* "are at present only minute, it is probable that in time there may be found out a way to collect a greater quantity of the electric fire, and consequently to increase the force of that power, which, by several of the experiments, if we are permitted to compare great things with small, seems to be of the same nature as thunder and lightning." It will at once occur to the readers of these lines how marvellously this prophecy of the sagacious old pensioner of the Charter House has been fulfilled in these later days, when, by the instrumentality of steam-driven magnets, a sufficient "quantity of the electric fire" is collected for the construction of miniature suns, competent to transform night into artificial day in the broad thoroughfares of our towns. It should also be remembered that it was not until forty-four years after Dr. Wall's experiments, and twenty-nine years after Stephen Gray's description of his spark, namely in 1752, that Dr. Franklin finally established the soundness of these early philosophical forecasts by actually drawing electrical sparks out of the thunder-cloud through the moist string of his kite, and by showing that these were in all respects identical with the sparks which were procured from electrical apparatus by artificial processes.

* "Philosophical Transactions," Vol. XXXIX.

The flash which appears when an electrical discharge passes through an interval of air is really exactly what it seems to be, and what it is familiarly called—a spark. It is incandescent matter. It is partly the air itself made to shine by the heat which is developed in the particles along the track of the transmission, and it is partly minute portions of the discharging body which have been torn off where the discharge occurs, and which are carried across the air-gap as a stream of impalpable and vapour-like substance. This, however, will be most easily understood by referring to what happens in the case where an arc of luminous flame is formed for the purpose of electrical illumination.

Two pencil-like points of charcoal are first made to touch each other by their tips, and a powerful stream of electrical force, generated by revolving magnets, is then turned on, so that it flows through them when they are thus resting in contact. The tips of the points are almost instantaneously made red-hot by the disturbance produced by the electrical current as it traverses the charcoal molecules. But if the red-hot tips are then gently drawn asunder for a little way a brilliant arch of flame presents itself in the gap. This is the appearance which is termed the voltaic arc, because it was in the first instance produced by the employment of the battery which the Italian Professor Volta contrived. The bright arch in this case is substantially composed of the vapour of charcoal, which is projected across from point to point, and which is kept at a shining white heat by the current of electricity that traverses the vaporised particles. The electricity first forms a vapour-bridge between the separated points, and then uses the bridge for its own passage across the gulf, but raises it to a red, or even white, heat by the impression which it makes upon the molecules as it traverses them. Particles of the intensely-heated charcoal are shot off as streams of luminous vapour from both points, but they issue in greater abundance from one point than they do from the other: from that, namely, which is impressed with the positive energy, on

account of its being more strongly heated by the discharge. The negative point acquires a dull red heat for a short distance away from the luminous arc, but the positive point is raised to a brilliant white heat much farther away. The positive point is soon hollowed out into a cup, on account of the rapid removal of its molecules as they are carried across the luminous arc, as is represented at P in Fig. 1.

Fig. 1.—Image of the Incandescent Points of Pencils of Charcoal when the Voltaic Arc is formed between them by the Passage of a Powerful Current of Electricity.

The negative point, on the other hand, is thickened at its base, and heaped round by a vast accumulated pile of the redundant molecules which have been transported across from the hollow cup, as is shown at N. This peculiarity is very beautifully and clearly seen when an enlarged image of the shining points is thrown upon a white screen by the instrumentality of an image-forming lens of glass like that which is used with the magic lantern. The luminous arc which intervenes between the shining points has the appearance of an oval flickering flame, through which, when it is closely watched, trains of sparkling particles may be seen now and again to be shot across. The positive point is consumed very much more rapidly than the negative one on account of the greater abundance of the particles that are carried away. In the case of the luminous arc, it appears to the eye as if there were a continuous and altogether unbroken electrical discharge sustained between the shining points. But this, in actual reality, is not the case. The flame is really composed of a series of discharges which follow each other in such rapid succession that the eye is not able to discern the intervals between. The apparent continuity and persistent maintenance of the flame is an illusion due to the circumstance that the visual impression of each consecutive discharge remains until the following one is stamped upon the eye. When a spark of electricity is drawn from an electrical machine so arranged as to make the discharge as long and brilliant as possible, the light marks out a track like that which is represented in the accompanying diagram (Fig. 2).

Fig. 2.—Representing the Zigzag Course followed by a long Electrical Spark during its discharge.

It runs along in a zigzag course, with short divergent branches thrown off from the external angles of the zigzag by the way. This luminous line is in reality a "crack" produced in the resisting substance of the air when the pent-up force breaks through the resistance. It is as much *a crack* as the one which is made in the glass when an over-intense charge breaks through the side of a Leyden jar. The only difference in the two cases is that the crack remains in the glass, but is immediately effaced in the fluid and movable substance of the air. That the light which is seen when such a spark passes through the air is simply the incandescent matter that is distributed along the track, is substantially proved when it is examined by the spectroscope as it passes. In such circumstances the spectral image which belongs to the particular matter that is brought to the shining state immediately appears. The vapours of copper and zinc which are carried across in an electrical spark passing between two brass balls * are as certainly detected in it by the spectroscope as the vapour of carbon is in the voltaic arc that is formed between pencils of charcoal.

But what is true in this case of the ordinary electrical spark is true also of lightning. The lightning, indeed, is merely a gigantic electric spark stretched out in the air for miles, instead of being limited to inches. Forked lightning quite strikingly resembles the spark represented in Fig. 2. M. Fusinieri, who gave a large amount of attention to this subject, was able to show that the vapour of iron, sulphur, and charcoal can at all times be detected in lightning, and also to prove that there is always an ample store of such substances floating in the air, and ready at hand to furnish a pabulum for its electrical fires. The lightning utilises the fuel of this kind which it finds in its path, but it also accomplishes some very marvellous freaks to acquire a yet further supply. There are well-known instances in which particles of gold have actually been transported through thick plates of silver by lightning. Picture frames are very commonly stripped of their gilding, and gold ornaments have been removed from the arms of living persons with the infliction of no more serious mischief than an unpleasant shock. It is only, how-

* The brass, it will be remembered, is itself a mixture of copper and zinc.

ever, it must be understood, when metallic substance is in a comparatively small mass, or when it constitutes the termination of a considerable conducting track, that disintegration and absorption of this kind take place. The discharge passes through a sufficiently large and continuous metallic mass without producing any dissipation or disintegration of its substance until it reaches the point where it bursts out from it as a spark.

Lightning not unfrequently melts metal conductors that are too large to be altogether disintegrated by the discharge, but not large enough to afford unimpeded transmission. This effect was known in very early times. Aristotle, in his book on "Meteorology," which was written three centuries and a half before the Christian era, alludes in it to copper plates having been melted off wooden shields by lightning. The old Roman authors, Seneca and Pliny, speak of gold, silver, and copper coins in a bag having been melted together without a wax seal upon the bag having been softened. A few years ago a German settler's house, standing upon the high road between the port and the capital of the colony of Natal, was struck by lightning, set fire to, and burned to the ground. In one part of the ruin a small tin box containing money was afterwards sought for; but the only remnant of this that could be found was a fragment of a half-sovereign in gold inseparably welded to a little piece of tinned sheet iron. The entire fragment weighed seventy-five grains, about thirty grains being gold and the rest iron. More than half of the gold coin had disappeared, and the remaining portion was eaten out into an irregular crescentic form, with one blunt horn projecting beyond the iron. The rest of the gold piece, comprising about one-third of a square inch of superficial area, was metallically connected with the iron by an actual brazing together of the particles of the iron and gold, and the tinned surface of the iron beyond the attachment was bronzed by a thin film of gold particles that must have been scattered over it at the instant of the brazing. The fragment of the iron plate is an inch long, and three-fifths of an inch broad. A marginal band of lighter coloured gold, that looks as if it were alloyed so far either with tin or iron, is set round the sinuous edge of the notch eroded into the half-sovereign, and there is a central "pivot-head" like spot in the middle of the weld which is characterised by a similar amalgam-like-hue.* M. Arago describes in one of his "Meteorological Essays," another more notable case, in which an iron chain used for drawing up corn into a windmill, in Lancashire, was struck whilst a weight was hanging from it, and in which the chain was found afterwards to have been converted into a solid bar by the fusing together of its links. Keys have in some well-authenticated instances been found firmly welded to the nails upon which they were hung, after a stroke of lightning. All these cases aptly illustrate and confirm the assumption that the transmission of powerful discharges of electricity through conductors is intimately connected with violent disturbance of their molecules.

* This curious specimen of metallic welding by lightning was exhibited by the author in the Loan Collection of Scientific Instruments at South Kensington, and is still contained in the residual portion of that collection.

INDEX.

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